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CONTROL OF INDUSTRIAL VOC EMISSIONS BY CATALYTIC INCINERATION
Volume 9. Quality Assurance

by

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EPA Contract 68-02-3171, Task 50

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16. ABSTRACT The report is part of a two-phase EPA effort to assess the performance, suitability, and costs of various technologies to control emissions of volatile organic compounds (VOCs). In Phase 1, information was assembled from the literature on the use and cost of using catalytic incineration for VOC control. Results included: (1) a review of current and developing catalytic incineration technology, (2) an assessment of the overall performance of catalytic incinerators, (3) a review of applications where catalytic incinerators are used, (4) a comparative analysis of catalytic incineration with other competing VOC controls, (5) an examination of available methods for emission testing catalytic incinerators, and (6) an assessment of the need for additional performance test data. Phase 2 was a test program designed to increase the catalytic incinerator performance data base. It resulted in reports documenting the performance of eight catalytic incinerators at six industrial sites. The incinerators were used to control VOC emissions from solvent evaporation processes at can coating, coil coating, magnet wire, and graphic arts printing plants. Performance was measured at several process conditions at each site. Incinerator performance was characterized in terms of destruction efficiency, outlet solvent concentration, and energy usage. Design and operating data were collected.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Magnet Wire	Pollution Control	13B	11F, 20C
Incinerators	Graphic Arts	Stationary Sources		14E
Catalysis	Printing Equipment	Catalytic Incineration	07D	
Organic Compounds		Volatile Organic Compounds	07C	
Volatility			20M	
Solvents		Solvent Evaporation	11K	
Evaporation		Can Coating		

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ABSTRACT

The emission of volatile organic compounds (VOCs) from industrial plants significantly increases ambient levels of photochemical oxidants, ozone, and smog. Control of industrial VOC emissions, therefore, can result in substantial environmental benefits. This study was part of a comprehensive effort by EPA/IERL-RTP to assess the performance, suitability and costs of various VOC control technologies. The objectives of the EPA program were two-fold:

(1) to provide an overview of how catalytic incineration is applied to control industrial VOC emissions and to assess the overall performance, applicability, and costs as compared to alternate VOC control technologies, and

(2) to gather actual performance data through a field testing program on existing operating industrial catalytic incinerators.

The task of meeting these objectives was accomplished in two phases. In the first phase, information was assembled from the literature on the use and cost of using catalytic incineration for VOC control. This phase of the study provides results in the following areas:

- A review of current and developing catalytic incineration technology,
- an assessment of the overall performance of catalytic incinerators,
- a review of applications where catalytic incinerators are used,
- a comparative analysis of catalytic incineration with other competing VOC controls,
- an examination of the available methods for emission testing catalytic incinerators, and
- an assessment of the need for additional performance test data.

The second phase was a testing program designed to increase the catalytic incinerator performance data base. The testing program was planned so that 8 catalytic incinerators at industrial sites would be tested.

The outputs from this phase of the program consisted of a series of reports documenting the performance of 8 catalytic incinerators at 6 industrial sites. All 8 incinerators were used to control VOC emissions from solvent evaporation processes. Incinerators at can coating, coil coating, magnet wire, and graphic arts printing plants were tested. The performance measurements were made at several process conditions at each of the sites visited. Incinerator performance was characterized in terms of destruction efficiency, outlet solvent concentration, and energy usage. Incinerator design and operating data, such as operating temperature, solvent type, catalyst volume and age, were collected to document the operating conditions during the tests.

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SECTION 1
INTRODUCTION

Radian Corporation, under contract to the U.S. Environmental Protection Agency (EPA Contract 68-02-3171, Work Assignment 50), performed site selection, test plan development, and performance tests of catalytic incinerators used for volatile organic compound (VOC) emissions control at industrial sites. VOC emissions are of concern to the EPA because they may react photochemically in the atmosphere to form photochemical oxidants. National Ambient Air Quality Standards (NAAQS) for photochemical oxidants are routinely exceeded in many areas of the United States.

The test objectives for this project were to characterize representative catalytic incinerators with respect to VOC destruction efficiency, providing a data base for assessment of catalytic incineration as a VOC control technology. Testing focused on the simultaneous monitoring of inlet and outlet VOC concentrations and measurement of incinerator operating conditions.

Performance tests conducted for this project incorporated a comprehensive quality assurance/quality control (QA/QC) program. The QA/QC program was designed to control data quality within acceptable limits and to provide a basis for estimating uncertainty associated with the measurement data. This report presents an assessment of data quality based on audit results, QC data, and performance test results. Section 2 is a brief summary of measurement data quality and conclusions based on the data quality assessment. QA/QC objectives are discussed in Section 3, and Section 4 describes the methods used in assessing data quality. Quality assurance audit procedures and results are discussed in Section 5, and quality control procedures and results are discussed in Section 6. Section 7 presents results of parametric analyses of incinerator performance, taken from test reports for the last three sites (Volumes 6-8), and provides a statistical assessment of validity of those results and conclusions.

SECTION 2
SUMMARY AND CONCLUSIONS

The assessment of overall performance of the catalytic incinerator testing program and associated data quality discussed in this report was based upon the performance and systems QA audits, internal QC data, and variability in the measurement data itself. Since the primary emphasis of the test effort was characterization of the incinerators with respect to VOC destruction efficiency, this report emphasizes assessment of error (i.e., uncertainty) associated with the destruction efficiency estimates and conclusions based on these estimates. This assessment indicates that uncertainty associated with these destruction efficiency estimates was generally within acceptable limits and was adequate to fulfill the objectives of the measurement program. It further indicates the conclusions presented in the Site Reports (Volumes 3-8), and in the Final Report (Volume 2) based on these estimates are both reasonable and valid.

While the performance audit data and QC data presented in this report provide the primary basis for evaluation of the quality of the destruction efficiency estimates, this evaluation requires careful interpretation of the audit and QC data, in the context of the measurement data and the manner in which it was used. For instance, although the Radian performance audit results indicated an average error (bias) of about -12% for Method 25A measurements, this does not translate into a corresponding error for measured destruction efficiencies.

Although performance audit results for both Method 18 and Method 25A measurements generally did not meet the ±10% accuracy objectives, inaccuracy observed in these measurements does not adversely impact destruction efficiency estimates nor conclusions based on these estimates. For a given destruction efficiency measurement, the absolute error in the measured efficiency is a function of systematic error (bias) plus random error (variability). Since destruction efficiency represents a ratio between inlet and outlet VOC measurements, absolute bias in the destruction efficiency value is a function of relative bias between inlet and outlet measurements. For comparisons of average destruction efficiencies measured under different operating conditions for a given incinerator, the validity of the conclusions is dependent only upon random error in the individual destruction efficiency estimates. Bias is not a factor since any bias would equally affect all destruction efficiencies measured using a given measurement system. Thus, the significance of results of parametric analyses may be evaluated statistically based upon variability in inlet and outlet measurement data. Data presented in Section 7 indicate that conclusions presented in the Interim Site reports pretaining to functional relationships between performance (destruction efficiency) and operating conditions were typically statistically valid at the 95% confidence level.

For comparisons of destruction efficiencies at different incinerators (i.e., using different measurement systems), relative bias between inlet and outlet mass flow measurements at each incinerator does become a factor in the uncertainty associated with individual destruction efficiency estimates and conclusions based on these estimates.

In order to examine the error, or uncertainty, which may be associated with any given destruction efficiency value, the combined effects of systematic error (bias) and random error were considered. Since, as discussed above, destruction efficiency represents a ratio between inlet and outlet VOC mass flow rates, absolute bias in the destruction efficiency value is a function of relative bias between inlet and outlet mass flow rate measurements. In estimating the magnitude of this absolute bias for a given destruction efficiency value, a "worst case" simulation was performed. For this "worst case" example, "typical" inlet and outlet VOC concentrations of 5000 ppmv-C and 250 ppmv-C, respectively, were used. A relative bias of 13.9% between inlet and outlet THC measurements was used, corresponding to that indicated by control sample data at Plant C-6. Similarly, liberal estimates of error were used for the other measurement parameters used in calculating destruction efficiency. Using these values, destruction efficiency was calculated both with and without correction for bias. The mean, uncorrected destruction efficiency was 94.5% with an approximate 95% confidence interval ranging from 94.0% to 94.9%. The mean destruction efficiency calculated with correction for bias was 93.6% with an approximate 95% confidence interval ranging from 92.7% to 94.2%. Thus, the bias effect for this "worst case" example averaged 0.9% and increased the confidence interval by 0.6%.

Quality assurance audits conducted during this program consisted of both performance and systems audits. The systems audit was a qualitative evaluation of overall performance with emphasis upon adequacy of the internal QC program and adherence to acceptable testing procedures, documentation, etc. This audit indicated generally acceptable performance although the testing procedures described in the Quality Assurance Project Plan (4) required some site-specific modifications. A discussion of the systems audit is presented in Section 5, while Section 8 deals with the procedural modifications.

Performance audit data are also presented in Section 5. These data include results for the audit conducted at Site C-3, as well as results for a similar audit conducted for the thermal incinerator test program conducted concurrently with this project using identical test methods. Results using propane audit standards indicated average error of about -12% for Method 25A measurements at Site C-3 and average error of about -46% for Method 18 measurements. At the thermal incinerator site, audit results for Method 18 indicated average error of about -4% while Method 25A results were about -11% and -4% at the inlet and outlet, respectively. Other audit standards were also used during the audits, and results are discussed in Section 5.

Statistical validation of parametric analyses presented in Section 7 was based upon observed variability in VOC measurement data during given test periods. Variability in these data includes sampling/analytical variability as well as temporal variability of the process. For Method 18 measurements, this variability was significantly greater than variability measured using propane control samples. Average (pooled) coefficients of variation for the Method 18 measurement data (THC values) ranged from about 3% to about 40% while within-day control sample precision (replicability) ranged from 0.4% to 3.2%. The greater error for the process measurements was probably due to analytical difficulty arising from the complexity of the sample gas streams.

For Method 25A measurements, the composition of the gas samples did not seem to have such a pronounced effect on measurement data variability. Within-day control sample precision for Method 25A ranged from about 0.4% to 2.3%. For three representative test periods at Site C-5, coefficients of variation for sample data averaged 1.2% and 2.4% at the inlet and outlet, respectively. A detailed discussion of measurement data variability for both methods is presented in Section 6.

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SECTION 3

QA/QC PROGRAM OBJECTIVES

With any measurement effort, some degree of uncertainty always exists due to inherent limitations of the measurement system. The purpose of the Quality Assurance/Quality Control (QA/QC) program associated with the incinerator testing was to provide a basis for estimates of this uncertainty and to control it within acceptable limits.

The quality assurance function was organized to provide independent review and assessment of project activities and their ability to achieve the stated data quality objectives. The QA Coordinator for the project had the responsibility of evaluating the adequacy and effectiveness of the QC system and providing assurance that it was, in fact, responsive to the specific needs of the program.

A quality control system is a system of routine internal procedures for assuring that the data output of a measurement system meets prescribed criteria for data quality. Inherent and implied in this control function is a parallel function of measuring and defining the quality of the data output. A well-designed internal QC program must be capable of controlling and measuring the quality of the data in terms of precision and accuracy, as well as ensuring that the data are complete, representative, and comparable. Precision reflects the influence of the inherent variability in any measurement system. Accuracy reflects the degree to which the measured value represents the actual or "true" value for a given parameter, and includes elements of both bias and precision. The precision and bias of the final data are related to the precision and bias of the component parts of the measurement system.

Both performance and systems audits were conducted by the QA Coordinator during the program. The performance audits were designed to provide a direct, quantitative, point-in-time assessment of data quality in terms of accuracy. This is achieved by using equipment and standards which are independent of those used by the field personnel. The systems audits were designed to provide a systematic, qualitative review and assessment of the critical elements of the various measurement systems and associated internal quality control (QC) systems, including chain-of-custody and documentation.

The overall objective of the QA/QC efforts was to provide the necessary information for defining the limits of error associated with the measurement data. While the system of QA activities was independent of the testing effort, *per se*, the QC system was an integral part of the daily technical effort. QC activities were designed to provide an overall system for generating data of a specified quality. The QA systems audit qualitatively assessed the adequacy of the internal QC system. The systems audit approach, observations, and recommendations are discussed in Section 5. Quantitative evaluation of data quality is based upon QC data (precision) and performance audit data (accuracy and precision) obtained during the program. Performance audit results are discussed in Section 5, and quality control data are presented in Section 6. Section 7 presents results of parametric analyses of incinerator performance for Plants C-4, C-5, and C-6, along with statistical data pertaining to the significance of observed functional relationships such as operating temperature *vs*. destruction efficiency.

SECTION 4

METHODS OF QUANTITATING DATA QUALITY

Internal quality control data associated with sampling/analytical aspects of the incinerator tests, along with performance audit results, and the measurement data themselves provide the basis for a quantitative assessment of measurement data quality. Specific performance audit and QC procedures used in collecting these data are discussed in Sections 5 and 6 of this report. This section discusses the procedures used to evaluate these data. Methods used in defining confidence intervals for destruction efficiency estimates, used in validating the results and conclusions for parametric analyses presented in Section 7, are also discussed in this section.

The quality control system for this measurement effort, in its broadest sense, included all procedures which ensured that the resulting measurement data were of adequate quality to fulfill the program objectives. Some procedures which fall into the category of QC were primarily intended to control data quality within acceptable limits (e.g., adherence to specified sampling and analytical procedures, calibration of instrumentation, careful documentation of field data and results, etc.). Other QC procedures were intended to provide data pertaining to precision (variability) and accuracy of the measurement data. In some cases, a single QC procedure might fulfill both control and assessment functions.

The purpose of this document is to provide quantitative estimates of the VOC measurement data quality, in terms of precision and accuracy. Therefore, the QC procedures discussed here will be limited to those which provide the basis for quantitating VOC data quality, including:

- Control sample analyses, and

- Repeat samples collected and analyzed under a given set of incinerator operating conditions.

4.1 DEFINITIONS OF PRECISION, ACCURACY, AND BIAS

Precision, by the definition presented in the EPA Quality Assurance Handbook, is "a measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions" (5). Different measures of precision exist, depending upon these "prescribed similar conditions." Radian typically uses the EPA definitions for replicability, repeatability, and reproducibility, as summarized in Table 4-1.

Accuracy is a measure of the degree of agreement between a measured value and the true value of the measured parameter. For single measurements, accuracy includes components of both bias and precision, i.e., both systematic and random error. Accuracy of the average of individual measurements equates accuracy with bias and represents an attempt to quantitate systematic error (bias) independent of random error (precision). The validity or significance of the estimate of bias is directly related to the number of individual measurements used to compute the average. It is based on the principle that as the number of individual measurements is increased indefinitely, the sample mean, $\overline{X}$, approaches a definite value, μ. The difference between μ and the true value, T, represents the magnitude of the measurement bias, or systematic error. The error in each individual measurement reflects this systematic error plus random error due to imprecision.

4.2 ASSESSMENT OF ACCURACY AND BIAS

Performance audits represent the primary mechanism for assessing accuracy of a measurement system. When a measurement system is challenged with an audit sample, the true value of which is known, the degree of agreement between the measured value and the true value reflects the accuracy of the measurement. The difference between the two is due to measurement error and includes both random error and systematic error (bias). This difference,

TABLE 4-1. MEASURES OF PRECISION

Source of Variability	Replicability	Repeatability	Reproducibility
Specimen (subsample)	Same or different	Same or different	Most likely diferent
Sample	Same	Same	Same
Analyst	Same	{At least one	Different
Apparatus	Same	of these must	Different
Day	Same	be different}	Same or different
Laboratory	Same	Same	Different

expressed as percentage of the true value, is often referred to as "relative accuracy," or simply "accuracy," although technically it represents inaccuracy.

Typically, repeated measurements are made of the parameter of interest for the same audit sample or of additional samples at different levels, and the average error is then calculated. As discussed in Section 4.1 above, this error value represents an estimate of measurement bias or systematic error, although it is also often referred to as "accuracy."

The significance of this bias estimate may be evaluated using confidence intervals. An approximate 95% confidence interval for the mean error can be calculated using:

$$\text{Mean}(\overline{X}) \pm t_{.025,(n-1)} \left(\frac{\text{Standard Deviation}}{\sqrt{n}} \right)$$

where n is the number of measurements used to compute the average and standard deviation and t is a table statistical value (.025 confidence level, n-1 degrees of freedom; when n is greater than 10, t approaches 2.0). For a particular set of nine measurements, assume an overall mean of 20 ppm is reported, and the standard deviation of these data is 10 ppm. Also, assume that the true concentration is 30. For these measurements, the 95% confidence interval is:

$$20 \pm 2.3 \left(\frac{10}{\sqrt{9}} \right)$$

$$\text{or } 20 \pm 7.7$$

which is the interval (12,28). Since this interval does not include the true value, 30 ppm, a conclusion of bias is justified. The magnitude of this bias is between 2 and 18 ppm. The uncertainty in the estimate is due to variability arising from random error.

For the audit data presented in Section 5, results are presented in terms of relative error where:

$$\text{Relative Error} = \frac{\text{Measured Value - True Value}}{\text{True Value}} \times 100$$

Results for a given method/instrument or for different concentration levels of a particular audit gas mixture (e.g., multipoint propane audits) are summarized in terms of "mean relative error," which represents an estimate of the bias of the measurement system. The standard deviation of relative error is also presented, which reflects variability in measurement error about the mean.

The control sample data presented in Section 6 may also be used to estimate bias for Method 18 and 25A VOC measurements. Tables 6-2 through 6-6, which summarize replicability for each site, include columns summarizing percent recovery for the control standards. Since the control standards were "certified" (±2% accuracy) standards, these relative recovery values reflect measurement bias, where 100% recovery represents 0% bias.

4.3 ASSESSMENT OF PRECISION

If a particular analytical method is known or assumed to be unbiased, i.e., free of systematic error, then accuracy of the results is limited only by random variability, i.e., by the precision of the measurements. For most standard or accepted analytical methods, random error is the major source of measurement error. Therefore, by quantitating random variability (i.e., precision) of the measurement data, a reliable estimate of uncertainty may be made.

For the VOC sampling/analytical procedures used in this program, the measurement data precision (i.e., random error) is a function of the combined effects of analytical variability and sampling variability. Each of these two sources of variability could be further subdivided into numerous specific components of variability such as that associated with calibration of the GC, that arising from fluctuations in detector response, temporal variability of the gas streams (i.e., process variability), etc.

The precision estimates presented in the subsequent sections are based on observed variability among replicate or repeat measurements made under various "prescribed similar conditions," selected for specific purposes. This variability was quantitated by first calculating the standard deviation for each set of measurements. The standard deviation is a measure of the average distance of individual observations from the mean. It is usually denoted s and defined as:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n-1}}$$

where n is the sample size,

X_i is the ith observation in the sample, and

$\overline{X}$ is the sample mean.

In order to facilitate comparison of variability at different concentration levels, measured variability is reported in terms of the coefficient of variation (also known as relative standard deviation) which is defined as:

$$CV = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100\%$$

When individual measurements of variability (i.e., CV) were combined (pooled) to obtain an overall measure of variability for a given set of conditions or measurements, the following technique was used:

$$\text{Pooled CV} = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 \quad DF_i}{\sum_{i=1}^{n} DF_i}}$$

where X_i = CV of data set i (e.g., CV for one duplicate pair, i),

DF_i = degrees of freedom for data set i (k_i-1)

n = total number of data sets (e.g., total number of duplicate pairs),

k_i = number of data points in set i (e.g., k=2 for duplicates),

i = data set 1,2,3 ... n

4.4 CONFIDENCE INTERVALS FOR DESTRUCTION EFFICIENCY

Conclusions pertaining to effects of various operating conditions (e.g., temperature, residence time, etc.) upon VOC destruction efficiency were based upon comparisons of destruction efficiencies measured under the conditions of interest. Uncertainty associated with each destruction efficiency estimate is expressed in terms of a confidence interval for the mean value. If, for a given pair (or set) of destruction efficiencies, there is no overlap in the calculated confidence intervals, the observed differences are considered to be statistically significant. On-site VOC determinations were accomplished using two methods, EPA Method 25A and the draft Method 18. Due to the limited amount of data taken using Method 18, confidence interval estimation was performed differently for the two methods. The confidence intervals reflect random sampling variation and random measurement error, with no adjustments for potential bias in the sampling and analytical methods (see Section 5 for a discussion on bias).

4.4.1 EPA Method 25A

While the distribution of the inlet and outlet VOC concentrations can both reasonably be assumed normal, the distribution of destruction efficiency (a function of the ratio of average outlet and inlet concentrations) may follow one of many possible forms. It was, therefore, not appropriate to apply conventional statistics for efficient estimation of the variance of destruction efficiency. Thus, a Monte-Carlo computer method was used to generate the confidence intervals.

This method involved regenerating the average destruction efficiency 400 times. Each time, inlet and outlet VOC concentrations were regenerated, except with an independent set of random variations. The distributional properties of the inlet and outlet VOC concentrations were used in computing the required random numbers.

For each of the 400 trials, sample estimates of inlet and outlet VOC concentration were computed. These estimates were then used to compute the average destruction efficiency. The 2.5 percent lower result and the 2.5 percent upper result from the 400 trials were then selected as the 95% confidence limits for the population mean destruction efficiency. These approximated 95% confidence limits can be interpreted as follows:

> When we state that the true mean destruction efficiency is within the confidence bounds, we expect to be correct about 95% of the time.

A Monte-Carlo simulation technique was also used for computation of correlation coefficients in order to take into account the variability associated with each mean destruction efficiency estimate.

4.4.2 Draft Method 18

In order to take into account the relatively small sample sizes for Method 18, approximate 95% confidence intervals for the mean destruction efficiency were obtained by combining the 80% confidence limits for the mean outlet and mean inlet VOC concentration as follows:

$$\text{lower 95\% limit for mean destruction efficiency} = 100\left(1 - \frac{O_U}{I_L}\right)$$

$$\text{upper 95\% limit for mean destruction efficiency} = 100\left(1 - \frac{O_L}{I_U}\right)$$

where, (O_L, O_U) is the 80% confidence interval for the mean outlet VOC concentration and (I_L, I_U) is the 80% confidence interval for the mean inlet VOC concentration. 80% was selected so that approximate 95% confidence intervals for mean destruction efficiency would result when the estimated mean inlet concentration was combined with the estimated mean outlet concentration. These 80% confidence intervals were derived simularly to those described in Section 4.2. The validity of using 80% was tested by comparing 95% confidence intervals derived from Monte-Carlo simulations to those derived using the above described technique for Method 25A results. These estimates differed by no more than ±0.05%.

The confidence intervals for mean destruction efficiency are conservative in the sense that 95% is a lower bound for the confidence coefficient for the intervals. The confidence intervals should be interpreted as follows:

> When we state that the true mean destruction efficiency falls within the limits computed as described above, we expect to be correct at least 95% of the time.

4.4.3 Evaluation of the Impact of Measurement Bias Upon Calculated Destruction Efficiency Values

In order to examine the error, or uncertainty, which may be associated with any given destruction efficiency value, the combined effects of systematic error (bias) and random error were considered. Since destruction efficiency represents a ratio between inlet and outlet VOC mass flow rates, absolute bias in the destruction efficiency value is a function of relative bias between inlet and outlet mass flow rate measurements. The magnitude of this absolute bias in a given destruction efficiency value can be better understood by looking at a "worst case" example. Table 4-2 presents the parameters used in computing a destruction efficiency value. Estimates of the mean value, bias and standard deviations for these parameters are given for this "worst case" example. Bias estimates for THC concentration were based upon results for the propane control sample analyses at Site C-6, which represent the greatest observed relative bias between inlet and outlet measurements. Estimates of mean and standard deviation presented represent "typical" test data values for Method 25A measurements. The potential bias in values used for solvent laden air (SLA), fuel, and combustion air flow rates was estimated and included in the calculations as a range with a mean of zero.

Using values presented in Table 4-2, destruction efficiency was calculated both with and without correction for bias. The mean, uncorrected destruction efficiency was 94.5% with an approximate 95% confidence interval ranging from 94.0% to 94.9%. The mean destruction efficiency calculated with correction for bias was 93.6% with an approximate 95% confidence interval ranging from 92.7% to 94.2%. Thus, the bias effect for this "worst case" example averaged 0.9% and increased the confidence interval by 0.6%.

These destruction efficiency estimates were calculated using the following equations:

$$\text{Destruction Efficiency (\%)} = \frac{\text{Mass Flow Rate (Inlet)} - \text{Mass Flow Rate (Outlet)}}{\text{Mass Flow Rate (inlet)}} \times 100$$

$$\text{where Mass Flow Rate} = \frac{12 \times \text{THC} \times \text{Flow Rate}}{10^6\ (0.024)},$$

$$\text{SLA Flow Rate (Inlet)} = \text{Total Flow Rate (Outlet)} - \text{Fuel Flow Rate} - \text{Combustion Air Flow Rate}$$

THC values were corrected for systematic error when calculating the destruction efficiency estimate corrected for bias. Confidence intervals were generated using a Monte Carlo computer simulation method as discussed above. In estimating the confidence intervals, assumptions were made about the distribution of the individual parameter estimates. While the distribution of the inlet and outlet VOC concentrations were assumed to be normal, the bias estimates for solvent laden air, fuel, and combustion air flow rates were assumed to be uniformly (i.e., rectangularly) distributed over the interval given in Table 4-2.

TABLE 4-2. VALUES USED IN ESTIMATING THE EFFECT OF MEASUREMENT BIAS UPON CALCULATED DESTRUCTION EFFICIENCY VALUES

Measurement Parameter	Mean	Std. Dev. of the Mean	Mean Relative Error, % (Bias)	Std. Dev. of the Mean Rel. Error
THC Conc. (ppmv-C) Inlet	5000	200	1.88	1.67
THC Conc. (ppmv-C) Outlet	250	5	-12.02	1.02
Flow Rate (SCFM) Outlet	5500	160	0	(-5,5)[a]
Fuel Flow Rate (SCFM)	35	0	0	(-15,15)[a]
Comb. Air Flow Rate (SCFM)	500	0	0	(-50,50)[a]

[a] Interval over which the bias is assumed to be uniformly distributed (i.e., rectangular distribution)

SECTION 5
QUALITY ASSURANCE AUDITS

A quality assurance audit of measurement efforts associated with this test program was conducted January 21-25, 1983 at Site C-3 by the QA Coordinator. Audit activities included performance audits of each of the analytical instruments, as well as a systems audit of the overall test effort.

The field testing efforts for this test program took place concurrently with virtually identical testing conducted under EPA Contracts 68-03-3038 WA SBR-011 and 68-02-3171 WA 62 to evaluate the performance of thermal incinerators used to control VOC emissions from industrial coating facilities. Two mobile laboratories, equipped with similar instrumentation, were used interchangeably for this program and the thermal incinerator program. A QA audit was performed for the thermal incinerator program at Site T-3, April 4-7, 1983. Since the sampling/analytical methods were identical for the two programs and the sampling teams, equipment, and instrumentation were used interchangeably for both programs, audit results for both audits are presented in this section.

5.1 PERFORMANCE AUDITS

Performance audits of the instrumentation used for gas phase sampling and analysis consisted of challenging the systems with audit gas mixtures at concentrations comparable to those in the incinerator inlet and outlet gas streams. Audit gas mixtures were obtained from both Scott Environmental Technology (certified, ±2% accuracy) and from the U.S. EPA, Quality Assurance Division, Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina (QA Audit Materials). At Site C-3 (catalytic incineration), performance audits included:

- Byron 401--THC (Method 25A)--outlet
- Byron 401--CO--outlet
- Tracor 560--THC (Method 25A)--inlet
- Antek--speciated hydrocarbons (Method 18)--inlet and outlet
- Fisher Gas Partitioner--CO_2 and O_2 (and N_2)--inlet and outlet

Gas phase measurement performance audits at Site T-3 (thermal incineration) included:

- Byron 401--THC (Method 25A)--outlet
- Byron 401--CO--outlet
- Byron 301--NMHC (Method 25A)--inlet
- Byron 301--CH_4--inlet
- Tracor 560--Speciated Hydrocarbons (Method 18)--inlet and outlet
- Fyrite Test Kit--CO_2 and O_2--inlet and outlet

Audit results for the audit conducted at Site C-3 are summarized in Table 5-1 and those for the audit conducted at Site T-3 are summarized in Table 5-2.

As indicated in Tables 5-1 and 5-2, only the Byron 301 (Method 25A, inlet) results for the propane multipoint audit at Site T-3, the Tracor 560 (Method 25A, outlet sample line) results for the propane multipoint at Site C-3, and Fisher (O_2 and CO_2) results at Site C-3 had average errors within the ±10% accuracy limits specified in the QA Project Plan (4). However, the major objective of the catalytic test program was to determine incinerator destruction efficiency under various operating conditions. Error, or inaccuracy, associated with any given destruction efficiency value reflects the combined effects of systematic error, or bias, and random error, or variability. Since destruction efficiency represents a ratio between inlet and outlet VOC mass flowrates, absolute bias in the destruction efficiency value is a function of relative bias between inlet and outlet mass flowrate measurements. Assuming negligible relative bias for volumetric flowrates, relative bias for mass flowrate is a function only of relative bias between

TABLE 5-1. SUMMARY OF PERFORMANCE AUDIT RESULTS - SITE C-3

Instrument	Parameter (Units)	Audit Standard	Audit Concentration Range	Mean Relative Error[1]	Standard Deviation[2]
Fisher Gas Partitioner	CO_2 (%)	CO_2 in N_2	1.0 - 15.9 (plus zero)	-7.4%	2.5%
	O_2 (%)	O_2 in N_2	1.3 - 21.2 (plus zero)	-0.46%	3.5%
Tracor (outlet)	THC (ppmv-C)	C_3H_8 in air	48 - 712 (plus zero)	-1.8%	15.4%
Tracor (inlet)	THC (ppmv-C)	C_3H_8 in air (plus C_2-C_{10} mixture for one point)	303 - 2159 (plus zero)	-12.3%	4.7%
Byron 401	THC (ppmv-C)	C_3H_8 in air	48 - 712 (plus zero)	-12.0%	7.1%
Byron 401	CO	CO in air	44 - 1010 (plus zero)	+19.9%	6.0%
Antek	ΣNMHC (ppmv-C)	C_2-C_{10} mixture	1100	-22.5%	--
Antek (outlet)	ΣNMHC (ppmv-C)	C_3H_8 in air	48 - 712	-45.5%	2.4%
Antek (inlet)	ΣNMHC (ppmv-C)	C_3H_8 in air	303 - 2159 (plus zero)	-46.2%	7.4%

[1] Average percent error for the measured concentration where % error = (measured conc. - actual conc.) x 100/actual conc.

[2] Standard deviation of the relative error; indicative of variability about the mean.

TABLE 5-2. SUMMARY OF PERFORMANCE AUDIT RESULTS - SITE T-3

Instrument	Parameter (Units)	Audit Standard	Audit Concentration Range	Mean Relative Error[a]	Standard Deviation[b]
Byron 401	THC (ppmv-C)	C_3H_8 in air (plus C_3H_8 in N_2 at one point)	78 - 303 (plus zero)	-10.8	1.8
Byron 401	THC (ppmv-C)	C_2-C_{10} mixture	1190	-20.5	---
Byron 401	THC (ppmv-C)	MEK in air	50	-23.1	---
Byron 301	NMHC (ppmv-C)	C_3H_8 in air (plus C_3H_8 in N_2 at one point)	303 - 2630	-4.2	4.8
Byron 301	NMHC (ppmv-C)	C_2-C_{10} mixture	1190	19.7	---
Byron 301	NMHC (ppmv-C)	MEK in air	50 - 820	-16.7	9.5
Byron 301	CH_4 (ppmv)	CH_4 in N_2	57	22	---
Byron 401	CO (ppmv)	CO in air and CO in N_2	44 - 1010	0.9	2.1
Tracor 560	TNMHC (ppmv-C)	C_3H_8 in air (plus C_3H_8 in N_2 at one point)	78 - 2631 (plus zero)	-4.2	5.3
Tracor 560	TNMHC (ppmv-C)	C_2-C_{10} mixture	1190	-19.5 (-16.0)[c]	---
Tracor 560	TNMHC (ppmv-C)	MEK in air	50 - 820	-60.1[c] (-42.2)[c,d]	34.6[c] (50.0)[c,d]
Tracor 560	CH_4 (ppmv)	CH_4 in N_2	57	44	---
Pyrite	CO_2 (%)	CO_2 in N_2	3.8	-30	---
Pyrite	O_2 (%)	O_2 in N_2	8.0 - 20.8	-8.2	13.1

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[a] Average percent error for the measured concentration where % Error = (Measured Conc. - Actual Conc.) x 100/Actual Conc.

[b] Standard deviation of the relative error; indicative of variability about the mean.

[c] Averages for 3 points (concentrations), where a value of "not detected" was reported for the lowest concentration, resulting in a relative error at that point of -100% (i.e., false negative).

[d] Based on results using RF's for individual species where available.

inlet and outlet concentration measurements. Thus, the magnitude of any absolute bias in either inlet or outlet measurements does not impact calculated destruction efficiencies. In other words, as long as the relative (percentage) bias in VOC measurements at the inlet is in the same direction (high or low) and of approximately the same magnitude as relative bias for outlet measurements, bias in the calculated destruction efficiency will be small. When two or more destruction efficiencies are compared, as in parametric analyses, the validity of the conclusions is dependent only upon random error, or variability, associated with the individual destruction efficiency estimates. Even relative bias is no longer a factor since any bias would equally affect all efficiencies measured using a given measurement system. So, while the performance audit results indicate that the VOC measurement data are not highly accurate in absolute terms, as would be required for emissions measurements, for instance, destruction efficiency estimates based on these data should be acceptably reliable since relative bias between inlet and outlet measurements was small, and the validity of conclusions based on parametric analyses may be assessed upon the basis of measurement data variability alone.

Detailed results for the audits at both sites are discussed in the remainder of this section. Results for each instrument are presented on the audit data forms in Appendix A.

5.1.1 Site C-3 Performance Audit Results

Except for the Method 18 (Antek) results, average error for all analyses was within ±20%. Results for the Antek indicated deficiencies in the Method 18 data, both qualitatively and quantitatively. Qualitatively, speciation of C_1 to C_6 hydrocarbons, as specified in the QA Project Plan, was not possible with the operating conditions required by the presence of heavy (C_{12} to C_{18}) organics. Methane and ethane could not be detected at all, and C_3 to C_5 species eluted simultaneously. While the speciation of C_2 to C_6 compounds was not particularly important, lack of methane data on the outlet will pose problems in comparing Method 25 THC data to Method 18 (Antec) data.

Also, results using an audit mixture containing C_1 to C_{10} normal alkanes plus iso-pentane, benzene and toluene indicated a problem of co-elution of certain species with boiling points above 80°C. These results are presented in Table 5-3. Apparently, benzene co-eluted with heptane and toluene co-eluted with octane. There was no way to determine the frequency of co-elution for the heavier (i.e., C_{12} to C_{18}) species.

Quantitatively, results for the Antek (Method 18) were poorer still. The multicomponent standard mentioned above was analyzed shortly after (~1 to 2 hours) calibration of the instrument. Based on THC concentration, the results were about 22% low. However, looking at error for individual species (or groups, such as C_3 to C_5), a trend of increasing error with increasing molecular weight is apparent. For C_3 to C_5, the measured value was 10.2% low while an error of -28% was indicated for C_{10}.

Audit results for two propane audit mixtures were worse than those for the multicomponent standard. Since the instrument was calibrated against propane, results using a propane audit standard should have been excellent. However, the measured values averaged 46% low over a concentration range of 48 ppmv-C to 2159 ppmv-C. Error ranged from -39% to -55%. Measurement error remained the same when the audit mixture was introduced directly into the instrument, bypassing the sample line, pumps, and manifold system. A calibration check using the propane calibration standard indicated less than 5% change since the previous calibration. Analytical results for the propane control standard were within normal limits. No reasonable explanation of these results could be derived.

Since the destruction efficiency estimates generated from the test data rely primarily upon Method 25A VOC measurements, the actual impact of the Method 18 results is minimal. Referring to Table 5-1, mean relative error for Method 25A (Tracor inlet THC and Byron 401 outlet THC) was -12.3% and -12.0% at the inlet and outlet, respectively. Thus, the average relative bias between the inlet and outlet measurements was less than 1%.

TABLE 5-3. DETAILED RESULTS FOR METHOD 18 (ANTEK) SPECIATION - SITE C-3

Component	Actual Conc. (ppmv-C)		Measured Conc. (ppmv-C)	Relative Error
	by species	Σ		
Ethane	48.4		ND	
Propane	19.8	165	148	-10.3
Butane	44.4			
Pentane	51.5			
Isopentane	49.2			
Hexane	48.2		38.7	-19.7
Benzene	306	358	293	-18.2
Heptane	51.7			
Toluene	368	427	334	-21.8
Octane	58.8			
Nonane	53.6			-23.5
Decane	58.3			-28.0

5.1.2 Site T-3 Performance Audit Results

Four types of audit standards were used to evaluate the Method 18 and Method 25A VOC measurements. First, each of the three instruments were challenged with several concentrations of propane in air, prepared by dilution of a high concentration (30,000 ppmv-C) standard plus one concentration of propane in nitrogen (an undiluted, NBS traceable mixture). Second, each instrument was challenged with a 12-component mixture containing C_2 to C_{10} aliphatics plus benzene and toluene. Finally, each instrument was challenged with various concentrations of methylethyl ketone (MEK) in air. A fourth standard, methane in nitrogen, was used to perform a single-point check of the Byron 301 methane analyses.

Since all three instruments were calibrated using propane, it is not surprising that the best performance audit results are those for the propane audit standards. Mean relative error (i.e., "average" error over the audit concentration range) was better than ±5% for the Tracor 560 and the Byron 301, and was about -11% for the Byron 401 for the propane audit standards. This measured error reflects the combined influences of calibration error (bias), random variability (precision), drift, and any error in the audit standards (approximately ±2%).

The C_2-C_{10} audit standard mixture was used to provide an estimate of the magnitude of error involved in the measurement of VOC concentration of a complex gas mixture, where different relative responses to different components of the mixture would introduce an additional source of error. For all three instruments, measured error was within ±20%. Interpretation of the audit results for the C_2-C_{10} mixture requires some further explanation. First, for the Method 18 results, the error values presented in Table 5-2 (-19.5% and -16.0%) represent the overall relative error, which is the percent error in the value for ΣNMHC obtained by adding the measured concentrations of each species (on a carbon basis) as compared to the sum of the known concentrations. The values for mean relative error in Table 5-4, on the other hand, were calculated by determining relative error for each species and then taking the average of these 12 values. Decane was not detected in the audit analysis, so the relative error for this compound was -100%. The parenthetical values in Table 5-4 were calculated omitting the error for decane and represent a better estimate of "average" error for those compounds which were detected (i.e., C_8 and lighter species).

A second consideration for the Method 18 audit results (and sample data) is the calibration basis for the results. Typically, the GC used for Method 18 analyses has been calibrated against a propane standard, so that all species concentrations were based on a propane-derived response factor. The idea was that, ultimately, response factors would be determined for all major components identified at the various sites, and the Method 18 data would be corrected for the differences in response. At Site T-3, however, actual response factors for 9 species were programmed into the integrator so that the "raw" Method 18 data was not on a propane response factor basis. By back-calculation to a propane response factor basis, estimates of error for "typical" raw Method 18 data were derived and are presented in Tables 5-2 and 5-4, along with error values for results based on individual species response factors, where available.

Due to the nature of Method 25A, the THC and NMHC results do not take into account differences in instrument (detector) response to different species in a sample mixture. These data should therefore be comparable to uncorrected Method 18 data (i.e., results based on a propane response factor). For the C_2-C_{10} audit mixture, relative error for the Byron 401 was -20.5% which agrees very well with the -19.5% overall error for the Method 18 analysis. The Byron 301 results were inconsistent, however, at 19.7% high. This was the only instance of a high NMHC measurement for the Byron 301, and there was no readily acceptable explanation for these results since measured values obtained using the Byron were low for both propane and MEK audit standards.

Since MEK was one of the three major solvents at Plant T-3, an MEK audit standard was also used for the performance audit. The Byron 301 and the Tracor 560 were each challenged with the same three concentrations ranging

TABLE 5-4. DETAILED RESULTS FOR METHOD 18 SPECIATION - SITE T-3

Component	Actual Conc. (ppmv-C)	Measured Conc. Using Propane RF (ppmv-C)	Measured Conc. Using Species RF (ppmv-C)	Relative Error Using Propane RF (%)	Relative Error Using Species RF (%)
Ethane	48.4	50.4	48.9	4.5	1.03
Propane	50.4	51.1	51.1	1.4	1.38
Butane	44.4	46.0	46.3	3.6	4.28
Isopentane	49.2	44.9	N/A	-8.7	--
Pentane	51.5	45.8	51.5	-11.0	0
Benzene	306	266	N/A	-13.0	--
Hexane	48.2	40.6	48.1	-15.8	-0.2
Toluene	368	307	331	-16.6	-10.0
Heptane	51.7	39.7	45.9	-23.1	-11.2
Octane	58.8	36.5	N/A	-37.9	--
Nonane	53.6	29.1	N/A	-45.7	--
Decane	58.3	ND	ND	-100	-100
		Mean Relative Error		-21.8 (-14.8)[a]	-14.3 (-2.1)[a]
		Standard Deviation[b]		29.0 (16.0)[a]	35.0 (6.0)[a]

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[a] Mean relative errors and standard deviations calculated omitting 100% error value for decane.

[b] Standard deviation of the relative error.

from 50 to 820 ppmv-C, while the 401 was challenged only with the low (50 ppmv-C) concentration. Similar errors were observed for both Byron instruments (-23.1% for the Byron 401 and -9.1% to -27.3% for the Byron 301). Method 18 results for the MEK standard did not compare well with the Method 25A results. The 50 ppmv-C (i.e., 12.5 ppmv MEK) standard was not detected using Method 18, and error at the other two concentrations was -40% based on the propane response factor. Based on the MEK response factor, the "corrected" Method 18 results were 13-14% low at the two detectable concentrations.

Both the Tracor GC and the Byron 301 were challenged with a methane audit standard at 57 ppmv. Both instruments gave high results for this standard, 44% (25 ppmv) for the Tracor and 22% (13 ppmv) for the Byron 301. A blank CH_4 concentration of ~5 ppmv was observed for the Tracor. Correcting for this blank reduces the error to 35%.

The Fyrite O_2 and CO_2 analyses were audited using mixtures of CO_2 in N_2 and O_2 in N_2 as well as ambient air. Results for the 3.8% CO_2 standard were 50% low while results for the 8.0% O_2 standard were 17.5% low. For ambient air, the O_2 analysis was accurate within 1.0%. Since the fixed gas composition of the sample gas streams was very close to that of ambient air, and since these measurements are used only to calculate gas molecular weight, the impact of the observed error on measured flow rates would be small.

The Byron 401 CO analyses were audited using two CO audit gas mixtures at 44 ppmv and 1010 ppmv. At the low concentration, the observed error was -0.6% while 2.4% error was observed at the high concentration for a mean relative error of 0.9%.

5.2 SYSTEMS AUDIT

A systems audit is an on-site qualitative review of the various aspects of a total sampling and/or analytical system to assess its overall effectiveness. It represents a subjective evaluation of a set of interactive systems with respect to strengths, weaknesses, and potential problem areas. The audit provides an evaluation of the adequacy of the overall measurement system(s) to provide data of known quality which are sufficient, in terms of quantity and quality, to meet the program objectives.

Systems audits of the various measurement systems used in the catalytic incineration program were conducted at the time of the on-site performance audit and during the off-site analytical effort. Prior to the field audit, checklists were prepared which delineated the critical aspects of the various methodologies using the work plan and Quality Assurance Project Plan (4) as guides. The checklists served as tools to direct the focus of the systems audits and to document relevant observations. Copies of these checklists are presented in Appendix B. The systems audits conducted for this program consisted of observing and documenting activities associated with the various measurement systems (sampling, monitoring, and analytical) employed in the carbon adsorption characterization efforts. The audits were designed to evaluate the following elements of the program:

- sampling and analytical procedures
- internal quality control procedures
- chain-of-custody procedures
- equipment and facilities
- calibration documentation, and
- data recording and validation

Overall, the systems audit indicated an effective, well-organized sampling/analytical effort which was judged to be adequate for achieving the program objectives. Documentation such as the master logbook was well organized and complete, as was the daily activity log. All equipment and instrument calibration data related to the field efforts were similarly complete and well organized.

Use of the microprocess-based (Apple II Plus computer) data acquisition/data reduction system for the Method 25A VOC measurements represented an effective approach in terms of QC for such a large amount of data. The software developed and used for these measurements included a routine which ensured that all QC checks were performed as specified and automatically compared QC results for drift checks, calibration, control sample analyses, blanks, etc. to the specified acceptance criteria. All QC data for Method 25A was stored on disk along with the measurement data. The extensive use of computerized data acquisition and data reduction was judged to be a significant contribution to the overall data handling effort.

Method 18 data, in the form of integrator printouts and data summary sheets, were also well organized. The field crew and analytical personnel exhibited an obvious familiarity with the equipment and methods used. Internal QC procedures were carefully followed.

Careful compliance with the specified procedures were generally observed for all sampling/analytical activities. Instances in which test procedures differed from those described in the QA Project Plan were typically related to site-specific requirements. For instance, analytical procedures described in the QA Project Plan for Method 18 indicated that reported species would include "methane, total C_2, C_3, C_4, C_5, C_6, C_{6+}." At Site C-3, however, the solvent used in the process consisted primarily of C_{12} to C_{18} organics. In order to maximize the usefulness of the data, Method 18 chromatographic conditions were selected to optimize detection of C_{12} to C_{18} species, sacrificing resolution of lighter (e.g., C_1 to C_6) species. At most sites, it was also not possible to adhere to discrete two-hour test periods as described in QA Project Plan. Rather, testing was scheduled to coincide with process operation, maximizing data capture.

The primary recommendations arising from the systems audit were:

- to locate the heated sample pumps upstream rather than downstream of the sampling line,

- to perform O_2 and CO_2 analyses at subsequent sites using a Fyrite test kit rather than a QC analysis, in the interest of saving analytical time for molecular weight determinations, and

- to keep analytical control charts more up-to-date

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SECTION 6
QUALITY CONTROL DATA

Internal QC procedures utilized in this program were designed to control data quality within acceptable limits and provide a basis for data quality assessment. A complete overview of the internal QC program may be found in the QA Project Plan prepared for this program. As with any measurement effort, a primary data quality consideration is measurement variability, or data precision. In this program, quality control sample analyses and analysis of replicate samples provided the mechanism for quantitating sampling/analytical variability. The use of specific acceptance criteria for these QC analyses provided the mechanism for controlling measurement data quality. Results of these QC analyses for the Method 18 and Method 25A VOC measurements, along with a discussion of procedures and acceptance criteria, are presented in this section.

6.1 CONTROL SAMPLE ANALYSES

Use of control standards was an important aspect of internal QC for the gas phase VOC measurements by Methods 18 and 25A. The purposes of the control standard analyses were:

- to control and assess within-day variability (replicability),
- to control and assess day-to-day variability (repeatability), and
- to provide a basis for assessing relative bias between inlet and outlet measurements.

Control sample data, with respect to replicability and repeatability are summarized in Table 6-1.

Gas mixtures of propane in nitrogen were used as control standards for both Method 18 and Method 25A analyses. These gases were certified standard mixtures (±2% accuracy), prepared at concentrations comparable to expected inlet and outlet VOC concentrations. While a control standard should optimally contain the same analyte(s) as the samples being analyzed, time and cost constraints were prohibitive for this program and propane was selected as an adequate compromise. During each test run, triplicate analyses of the control standard were performed by introduction of the sample through the complete sampling/analytical system, including pumps, sample line, and manifold. In this way, the control sample was analyzed in the same manner as an actual sample.

Control standard analyses were required following each instrument calibration, prior to use during testing. In most cases, the control samples were analyzed daily. Acceptance criteria for the VOC control sample analyses were:

- CV $\leq$ 5% for triplicate analyses, and
- Mean analysis value within ±10% of the overall (running) mean for previous analyses.

Table 6-1 represents a summary of the variability data presented in Tables 6-2 through 6-11, which are detailed results for each site. Repeatability and replicability values in Table 6-1 are pooled (i.e., "average") coefficients of variation for each method/site. Relative recovery data, presented along with replicability data in Tables 6-2 through 6-6, represent the mean measured concentrations for the control samples expressed as a percentage of the "true" concentrations. These data are useful as a measure of relative bias between inlet and outlet

TABLE 6-1. SUMMARY OF VOC CONTROL SAMPLE DATA

Site	Method 18		Method 25A	
	Replicability (CV)[a]	Repeatability (CV)[a]	Replicability (CV)[a]	Repeatability (CV)[a]
1	2.34	2.00	2.09	5.61
3	1.35	4.53	0.95	3.37
4	0.76	2.95	1.76	3.79
5	0.45	1.55	0.86	3.19
6	0.65	1.58	0.85	3.19

[a] Pooled coefficient of variation where: $CV = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$

TABLE 6-2. RESULTS OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-1

INSTRUMENT	ANALYSIS DATE	NUMBER OF REPLICATES	MEAN RESPONSE (PPMV)	MEAN % RECOVERY	CV (%)	POOLED BY INSTRUMENT % RECOVERY	POOLED BY INSTRUMENT CV (%)
BYRON 301	13NOV82	3	314.00	95.8	2.30	98.5	2.22
	15NOV82	3	314.67	96.1	2.16		
	18NOV82	3	328.47	100.3	1.11		
	20NOV82	3	326.67	99.7	0.64		
	22NOV82	3	322.33	98.4	0.36		
	23NOV82	3	329.00	100.4	4.21		
BYRON 401	13NOV82	3	9.19	92.5	0.00	96.0	1.97
	15NOV82	3	8.56	86.2	0.00		
	18NOV82	3	10.67	107.9	3.08		
	20NOV82	3	9.91	99.6	0.00		
	22NOV82	3	9.30	93.7	1.74		
	23NOV82	3	9.54	96.1	3.27		
HP GC	11NOV82	3	3.21	97.0	3.51	96.6	3.24
	15NOV82	3	3.22	97.3	4.35		
	16NOV82	3	3.16	95.6	0.48		
TRACOR GC	11NOV82	3	327.00	99.7	0.61	99.4	1.83
	15NOV82	3	313.00	95.4	1.94		
	16NOV82	3	326.33	99.5	3.36		
	19NOV82	3	338.33	103.2	1.92		
	20NOV82	3	325.67	99.3	0.18		
	22NOV82	3	326.00	99.4	1.87		
	23NOV82	3	326.33	99.5	0.88		

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TABLE 6-3. RESULTS OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-3

INSTRUMENT	ANALYSIS DATE	NUMBER OF REPLICATES	MEAN RESPONSE (PPMV)	MEAN % RECOVERY	CV (%)	POOLED BY INSTRUMENT % RECOVERY	POOLED BY INSTRUMENT CV (%)
ANTEK-1B/IN	21JAN83	3	944.70	96.3	1.42	96.7	1.56
	22JAN83	3	906.23	92.4	0.55		
	23JAN83	3	996.37	101.6	0.22		
	24JAN83	3	941.33	96.0	0.72		
	27JAN83	3	978.00	99.7	3.38		
	28JAN83	3	927.67	94.6	0.59		
ANTEK-1B/OT	21JAN83	3	93.51	94.6	1.50	95.5	1.11
	22JAN83	3	86.18	87.1	0.78		
	23JAN83	3	97.47	98.6	1.35		
	24JAN83	3	91.63	92.7	0.56		
	27JAN83	3	98.04	99.1	1.45		
	28JAN83	3	99.93	101.0	0.49		
BYRON 401-25A/OT	19JAN83	3	107.60	108.8	0.00	103.6	1.24
	20JAN83	3	101.90	103.0	0.00		
	22JAN83	3	101.57	102.7	0.97		
	23JAN83	3	108.50	109.7	0.00		
	24JAN83	3	99.24	100.3	2.85		
	27JAN83	3	99.57	100.6	1.33		
	28JAN83	3	98.99	100.1	0.00		
TRACOR-25A/IN	19JAN83	3	923.67	94.1	0.35	92.5	0.37
	20JAN83	3	903.00	92.0	0.11		
	23JAN83	3	914.33	93.1	0.13		
	24JAN83	3	942.00	96.0	0.18		
	27JAN83	3	877.33	89.4	0.76		
	28JAN83	3	886.67	90.3	0.23		

TABLE 6-4. RESULTS OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-4

INSTRUMENT	ANALYSIS DATE	NUMBER OF REPLICATES	MEAN RESPONSE (PPMV)	MEAN % RECOVERY	CV (%)	POOLED BY INSTRUMENT	
						% RECOVERY	CV (%)
BYRON 301-25A/IN	31JAN83	3	335.40	102.5	0.46	98.6	0.55
	01FEB83	3	331.20	101.2	0.89		
	02FEB83	3	309.90	94.7	0.56		
	03FEB83	3	328.37	100.4	0.28		
	04FEB83	3	308.83	94.4	0.30		
BYRON 401-25A/OT	31JAN83	3	98.00	97.4	1.43	100.6	2.43
	01FEB83	3	98.20	97.6	4.04		
	02FEB83	3	106.50	105.9	1.79		
	03FEB83	3	103.87	103.2	1.51		
	04FEB83	3	99.70	99.1	2.37		
TRACOR-18/IN	31JAN83	3	979.01	99.8	0.51	100.4	0.85
	01FEB83	3	998.67	101.8	1.78		
	02FEB83	3	992.33	101.2	0.21		
	03FEB83	3	961.33	98.0	0.12		
	04FEB83	3	991.33	101.1	0.32		
TRACOR-18/OT	31JAN83	3	104.33	103.7	1.11	101.9	0.66
	01FEB83	3	104.33	103.7	0.55		
	02FEB83	3	102.67	102.1	0.56		
	03FEB83	3	105.67	105.0	0.55		
	04FEB83	3	95.63	95.1	0.22		

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TABLE 6-5. RESULTS OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-5

INSTRUMENT	ANALYSIS DATE	NUMBER OF REPLICATES	MEAN RESPONSE (PPMV)	MEAN % RECOVERY	CV (%)	POOLED BY INSTRUMENT % RECOVERY	POOLED BY INSTRUMENT CV (%)
BYRON 401-25A/OT	15FEB83	3	96.50	95.9	0.90	91.1	1.16
	16FEB83	3	92.33	91.8	0.88		
	17FEB83	3	88.60	88.1	0.00		
	18FEB83	3	89.33	88.8	1.95		
HP-18/IN/OT	16FEB83	3	100.03	99.4	0.32	98.6	0.45
	17FEB83	3	100.10	99.5	0.53		
	19FEB83	3	97.40	96.8	0.47		
TRACOR 560-25A/IN	15FEB83	3	941.70	96.0	0.47	98.2	0.36
	16FEB83	3	987.67	100.7	0.31		
	17FEB83	3	974.67	99.4	0.06		
	19FEB83	3	949.00	96.7	0.46		

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TABLE 6-6. RESULTS OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-6

INSTRUMENT	ANALYSIS DATE	NUMBER OF REPLICATES	MEAN RESPONSE (PPMV)	MEAN % RECOVERY	CV (%)	POOLED BY INSTRUMENT	
						% RECOVERY	CV (%)
BYRON 601-25A/IN	24FEB83	3	315.67	96.5	0.18	101.9	0.75
	28FEB83	3	325.33	99.4	0.99		
	01MAR83	3	343.00	104.8	0.87		
	02MAR83	3	341.00	104.2	0.51		
	04MAR83	3	342.00	104.5	0.88		
BYRON 401-25A/OT	24FEB83	3	84.50	84.0	1.23	88.0	0.94
	28FEB83	3	88.63	88.1	0.26		
	01MAR83	3	89.63	89.1	0.45		
	02MAR83	3	90.07	89.5	0.90		
	04MAR83	3	89.70	89.2	1.35		
TRACOR 560 -18/IN	24FEB83	3	946.50	96.4	0.69	98.6	0.35
	28FEB83	3	958.77	97.7	0.08		
	01MAR83	3	975.07	99.3	0.26		
	02MAR83	3	978.13	99.6	0.12		
	04MAR83	3	978.67	99.7	0.19		
TRACOR 560-18/OT	24FEB83	3	102.33	101.7	0.85	101.5	0.97
	28FEB83	3	103.80	103.2	1.42		
	01MAR83	3	100.21	99.6	0.28		

TABLE 6-7. DAY-TO-DAY VARIABILITY (REPEATABILITY) OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-1

INSTRUMENT	NUMBER OF DAYS	MEAN RESPONSE (PPMV)	COEFFICIENT OF VARIATION (CV %)
BYRON 301	6	322.52	2.10
BYRON 401	6	9.53	7.65
HP GC	3	3.20	0.95
TRACOR GC	7	326.10	2.25

TABLE 6-8. DAY-TO-DAY VARIABILITY (REPEATABILITY) OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-3

INSTRUMENT	NUMBER OF DAYS	MEAN RESPONSE (PPMV)	COEFFICIENT OF VARIATION (CV %)
ANTEK-18/IN	6	949.05	3.48
ANTEK-18/CT	6	94.46	5.38
BYRON 401-25A/OT	7	102.48	3.88
TRACOR-25A/IN	6	907.83	2.64

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TABLE 6-9. DAY-TO-DAY VARIABILITY (REPEATABILITY) OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-4

INSTRUMENT	NUMBER OF DAYS	MEAN RESPONSE (PPMV)	COEFFICIENT OF VARIATION (CV %)
BYRON 301-25A/IN	5	322.74	3.86
BYRON 401-25A/OT	5	101.25	3.72
TRACOR-18/IN	5	984.54	1.50
TRACOR-18/OT	5	102.53	3.90

TABLE 6-10. DAY-TO-DAY VARIABILITY (REPEATABILITY) OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-5

INSTRUMENT	NUMBER OF DAYS	MEAN RESPONSE (PPMV)	COEFFICIENT OF VARIATION (CV %)
BYRON 401-25A/OT	4	91.69	3.91
HP-18/IN/OT	3	99.18	1.55
TRACOR 560-25A/IN	4	963.26	2.24

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TABLE 6-11. DAY-TO-DAY VARIABILITY (REPEATABILITY) OF PROPANE CONTROL SAMPLE ANALYSES AT SITE C-6

INSTRUMENT	NUMBER OF DAYS	MEAN RESPONSE (PPMV)	COEFFICIENT OF VARIATION (CV %)
BYRON 401-25A/IN	5	333.40	3.68
BYRON 401-25A/OT	5	88.51	2.60
TRACOR 560 -1B/IN	5	967.43	1.47
TRACOR 560-1B/OT	3	102.11	1.77

measurements. They are not, however, intended to be accurate measures of absolute bias for the sample data, as discussed in Section 5.

The control sample analysis data contained in Tables 6-2 through 6-11 are graphically illustrated in Figures 6-1 through 6-10. In each graph, the running mean of the analyses is represented by a solid line. Dotted lines mark the ±10% control limits. Individual analysis values are represented by a symbol "X", and mean values for each day are denoted by "□". These charts illustrate replicability by the scatter of "X"s for a given day and repeatability as the day-to-day variability of the mean values.

A review of the data presented in Tables 6-2 through 6-6 shows that instrumentation used at each facility exhibited excellent replicability for the control standards, attaining CVs well within the ≤5% acceptance criteria.

Repeatability, or day-to-day variability, for Method 18 and 25A control sample data is summarized by site in Tables 6-7 through 6-11. These data reflect total sampling/analytical variability over time, and constitute a more conservative estimate of actual measurement variability than estimates for replicability. With the exception of the Byron 401 control sample data for Site C-1, which exhibited a CV of 7.65, repeatability for all sites was within 5% (CV).

6.2 REPLICATE SAMPLE ANALYSES

As discussed in the Quality Assurance Project Plan for this project, the draft version of Method 18 prescribes triplicate analyses of each sample to assess analytical replicability. Obviously, this is not possible when using a direct interface sampling approach. However, replicate samples were collected and analyzed for most sets of process conditions. Variability for these analyses includes sampling/analytical variability, as well as temporal variability due to process fluctuations. These data are presented for each site in Tables 6-12 through 6-16. The coefficient of variation is presented

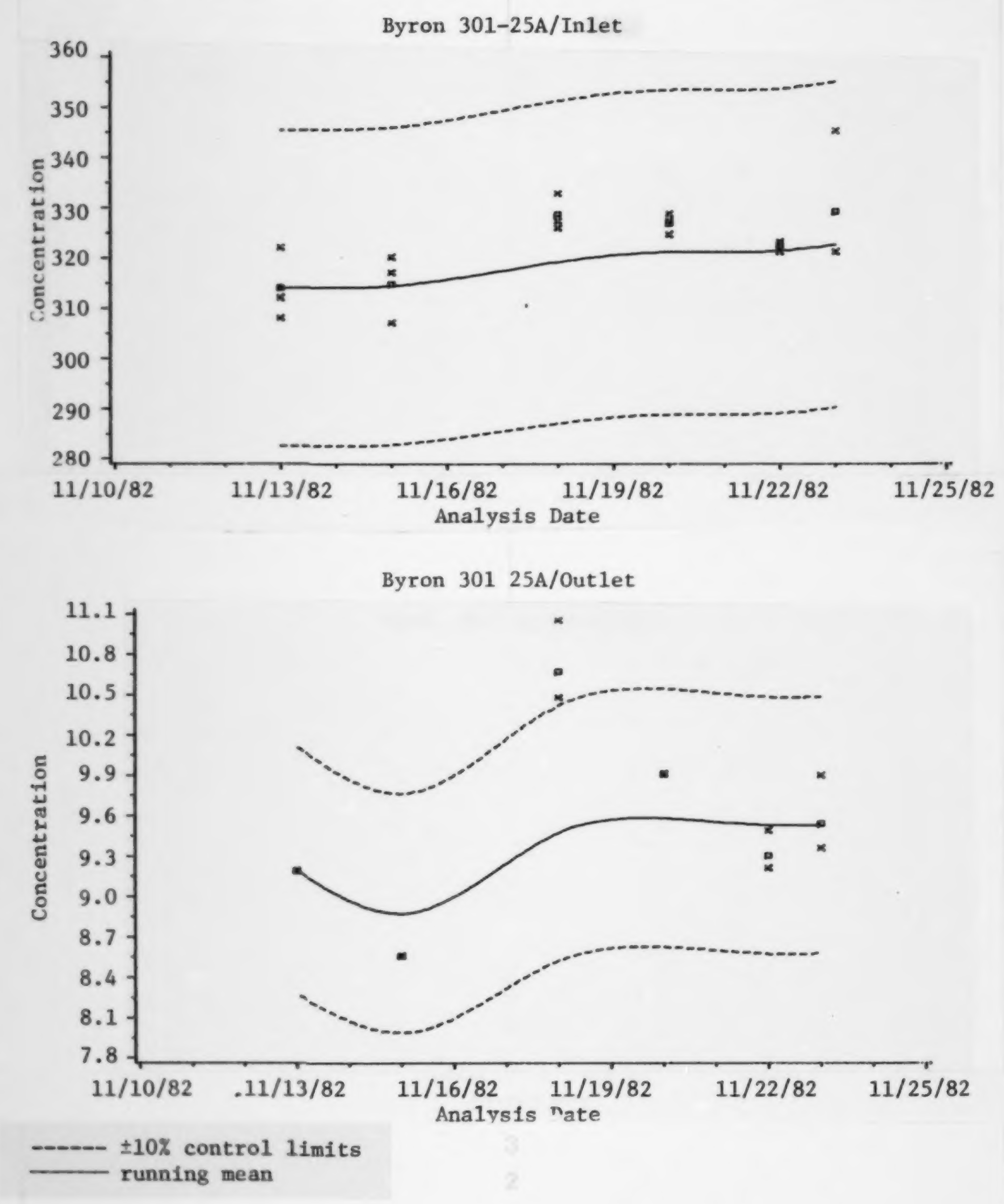


Figure 6-1. Method 25A Control Sample Data for Site C-1

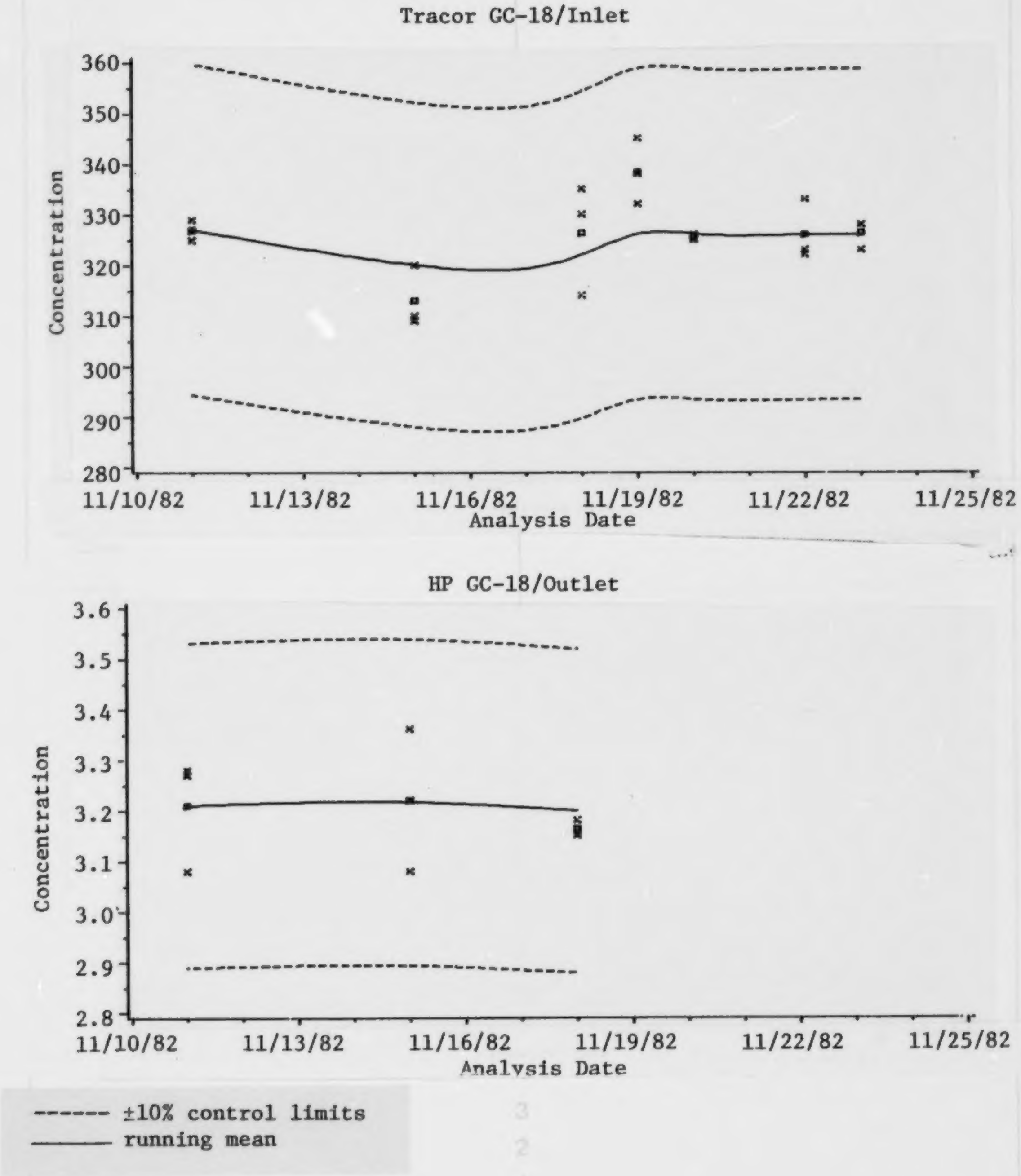


Figure 6-2. Method 18 Control Sample Data for Site C-1

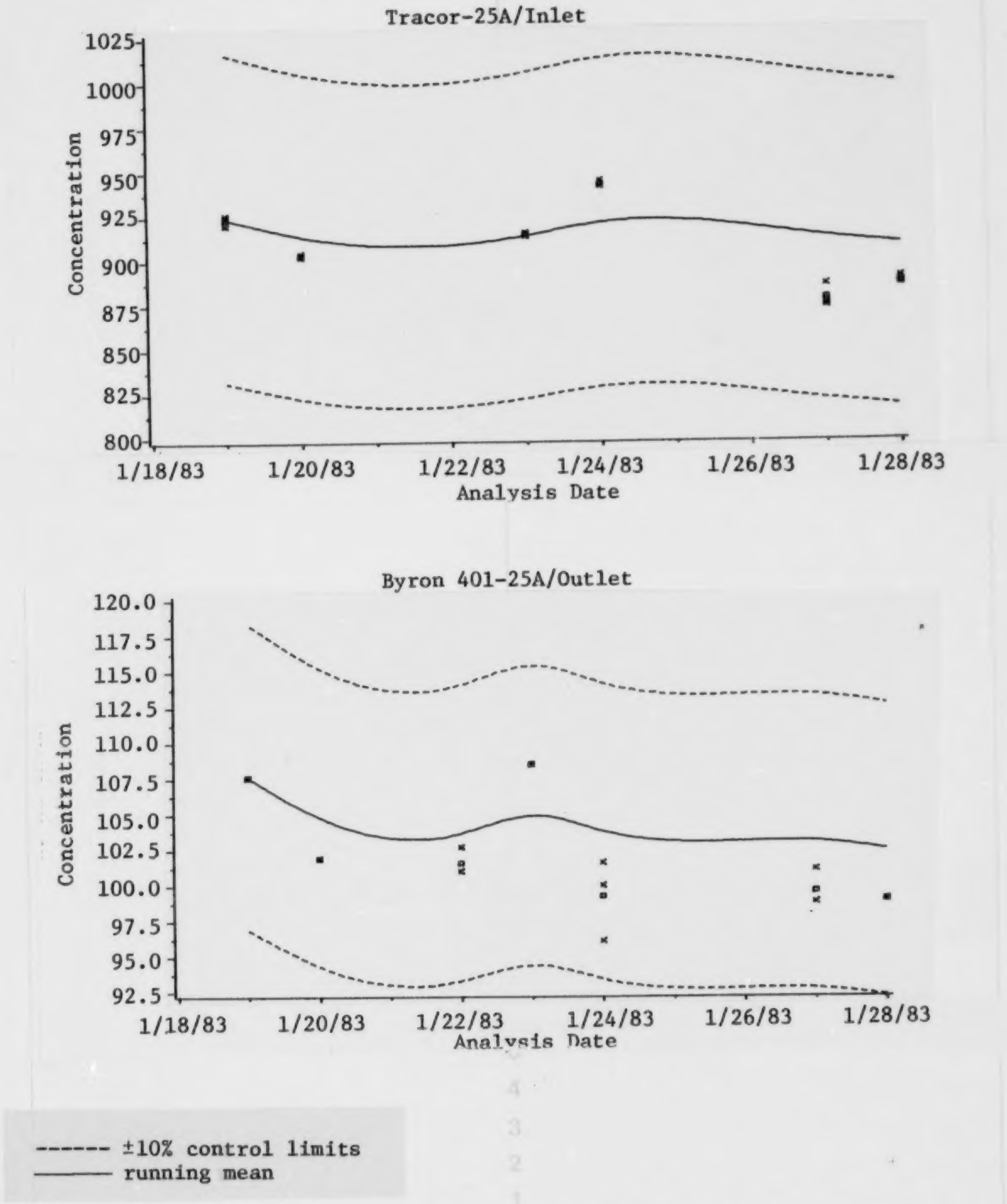


Figure 6-3. Method 25A Control Sample Data for Site C-3

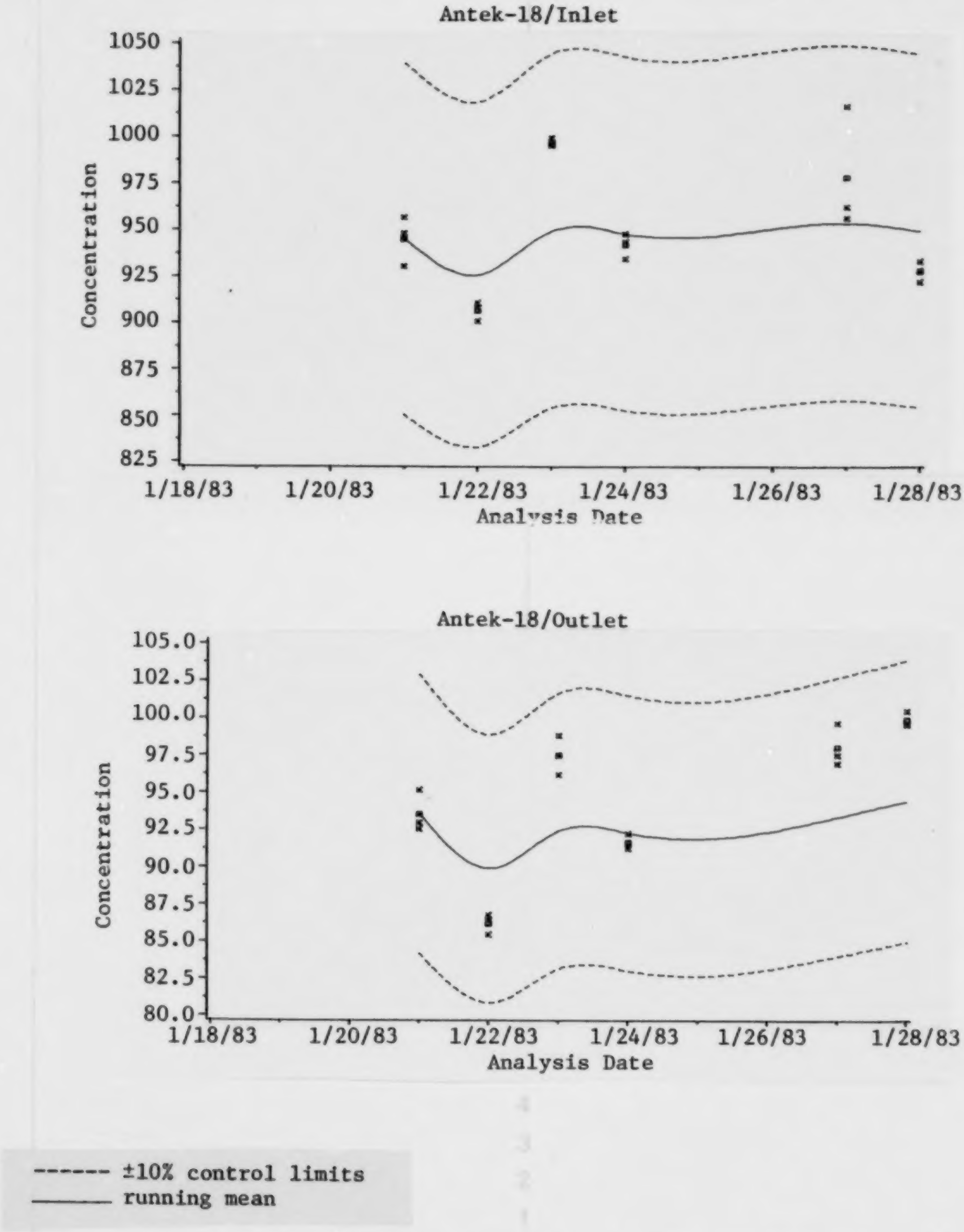


Figure 6-4. Method 18 Control Sample Data for Site C-3

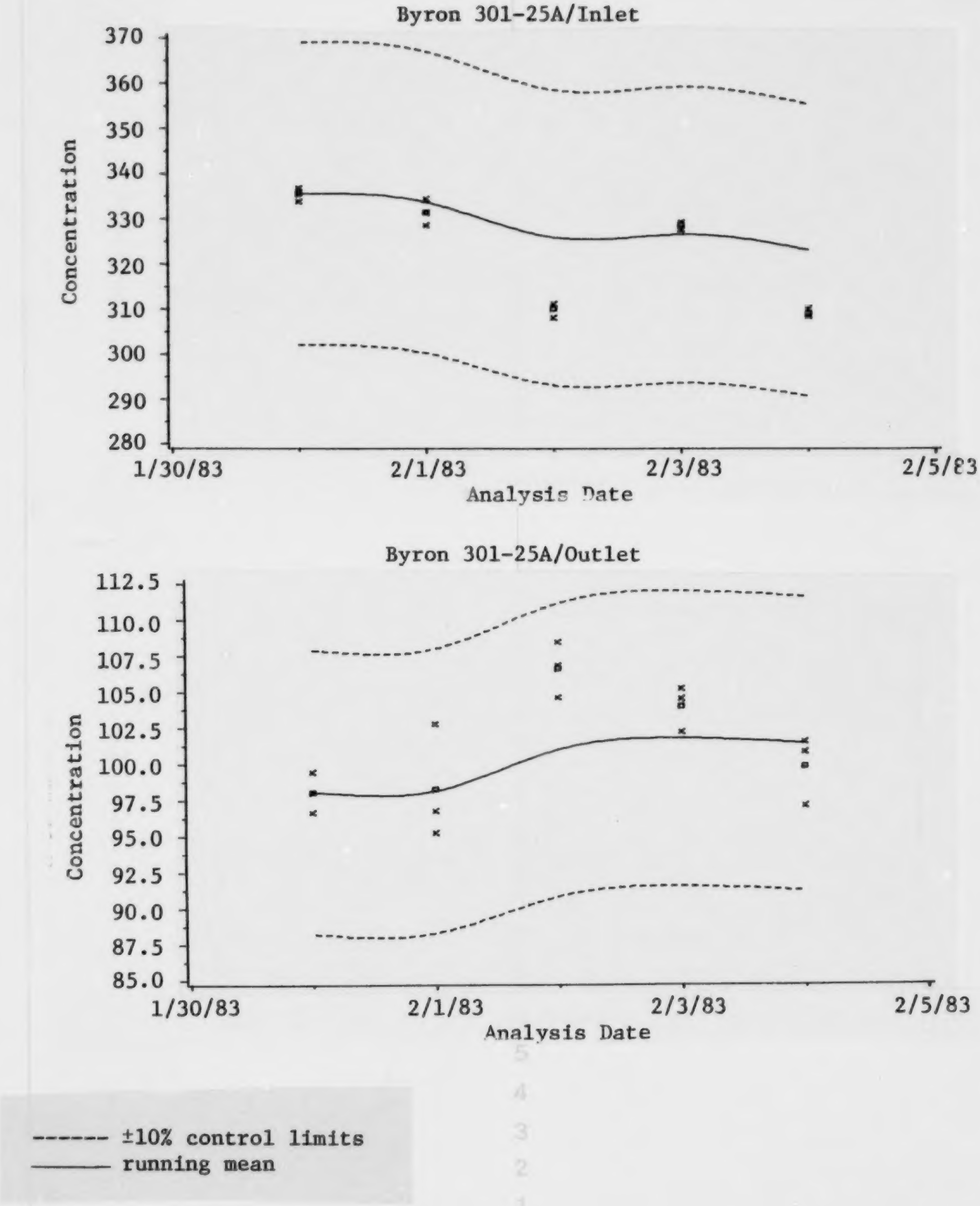


Figure 6-5. Method 25A Control Sample Data for Site C-4

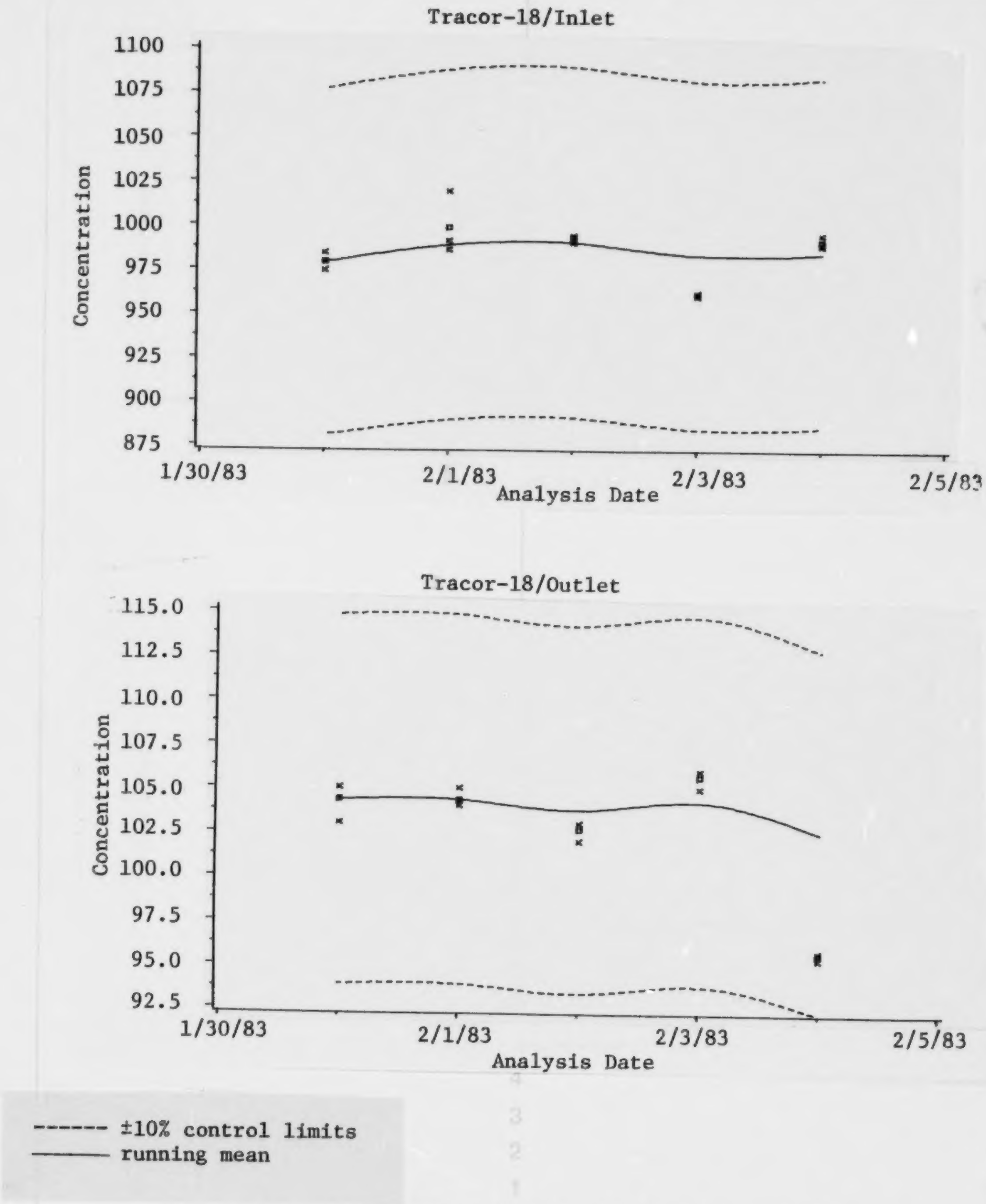


Figure 6-6. Method 18 Control Sample Data for Site C-4

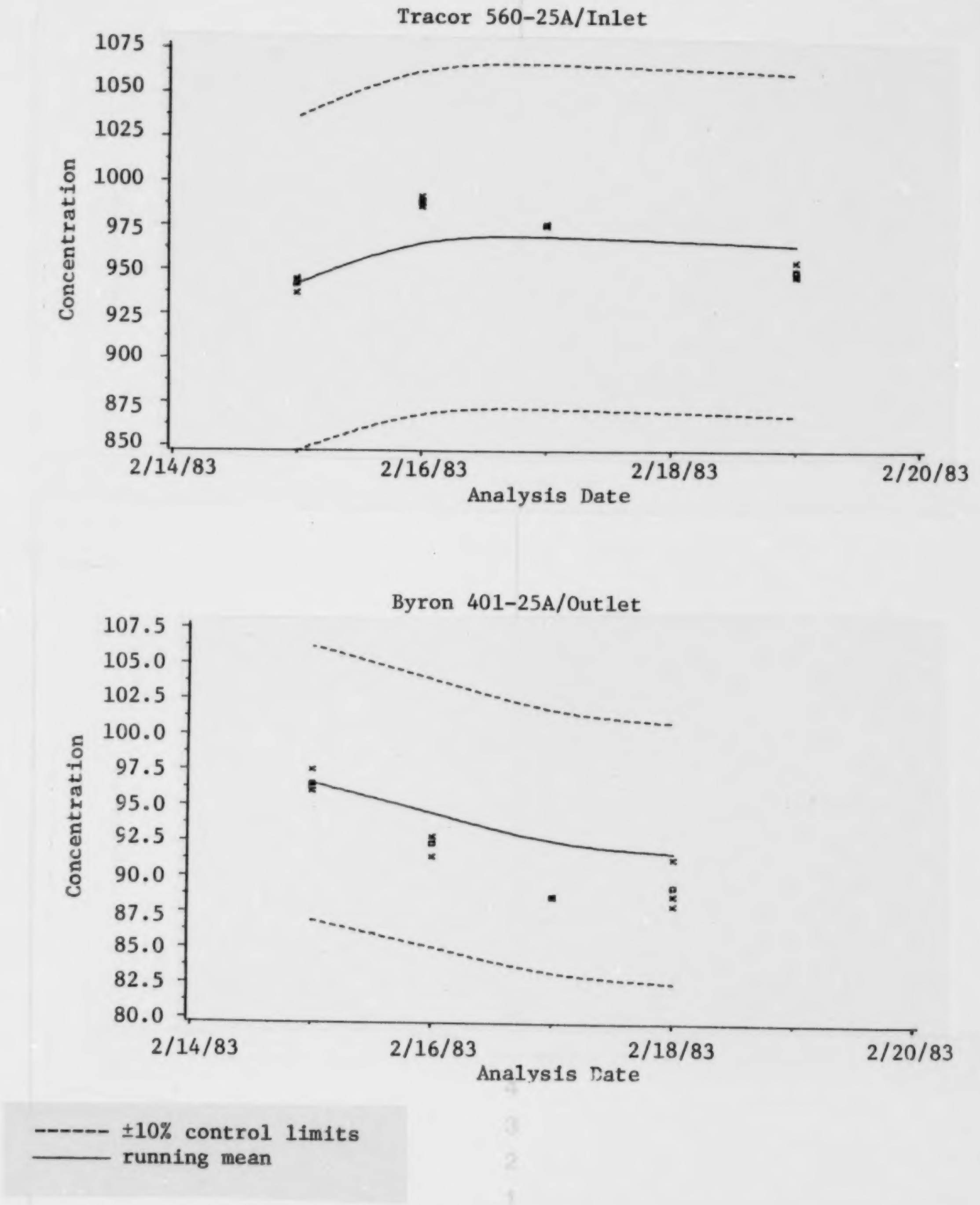
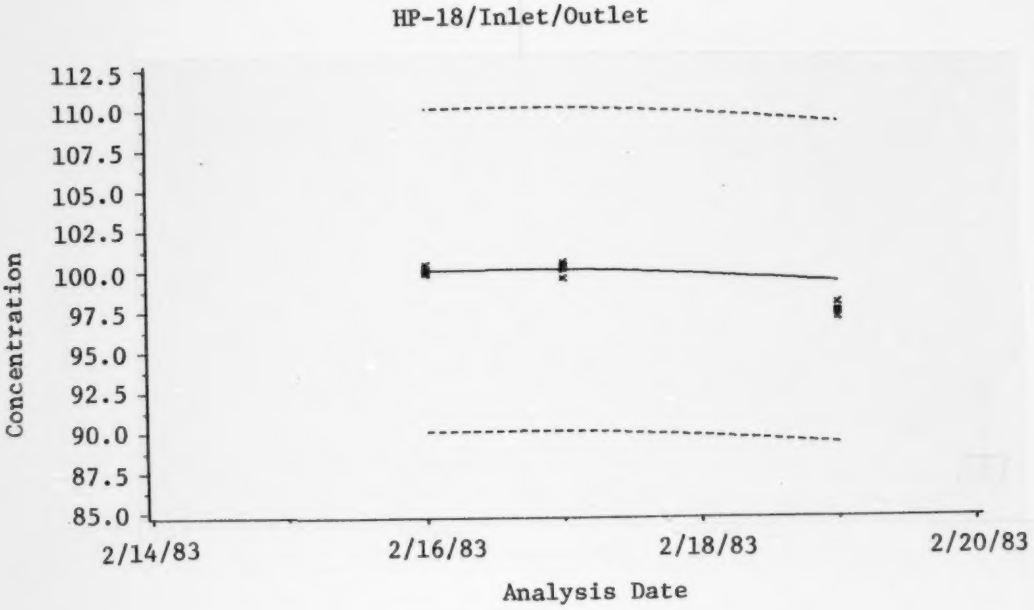


Figure 6-7. Method 25A Control Sample Data for Site C-5



------ ±10% control limits
——— running mean

Figure 6-8. Method 18 Control Sample Data for Site C-5

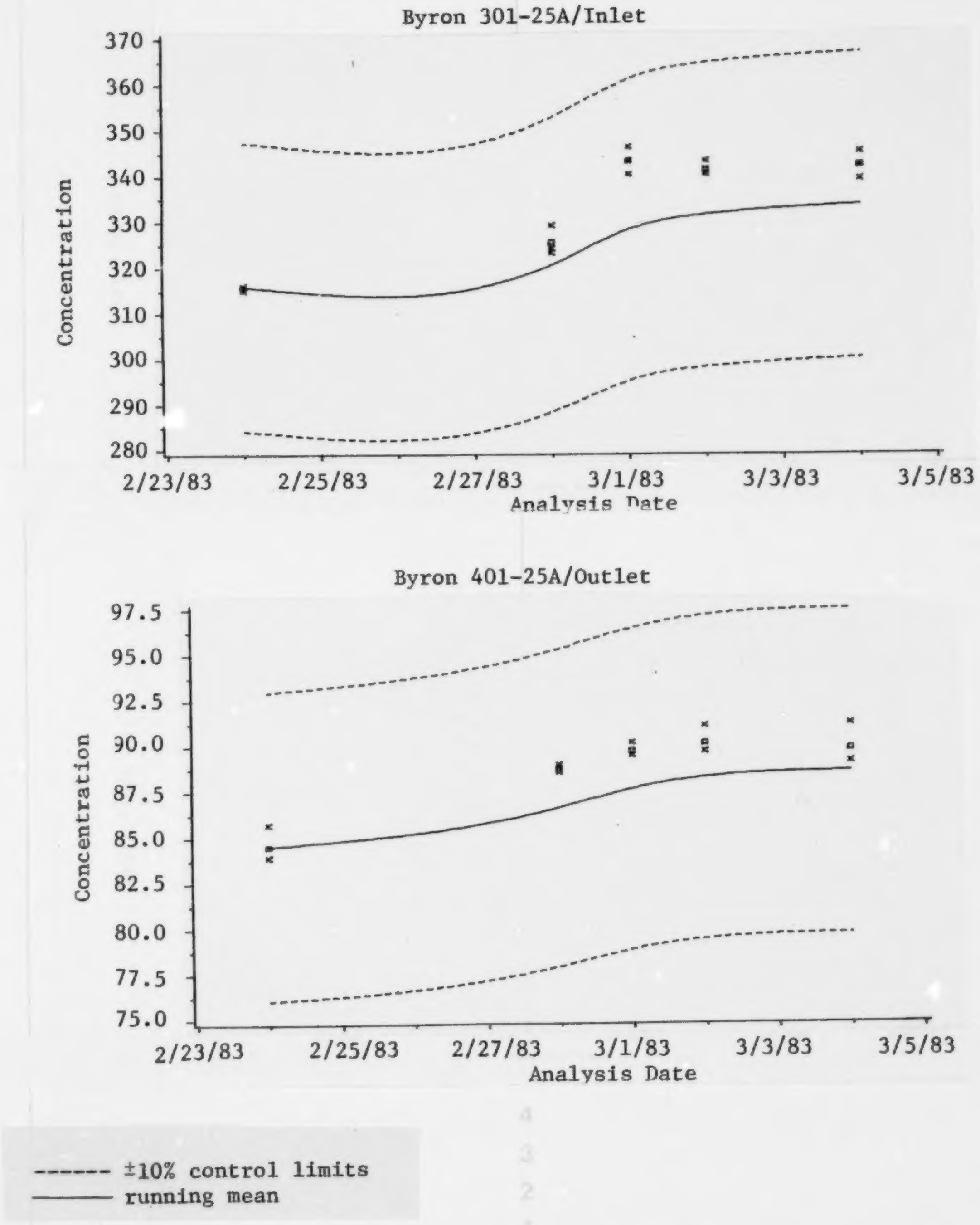


Figure 6-9. Method 25A Control Sample Data for Site C-6

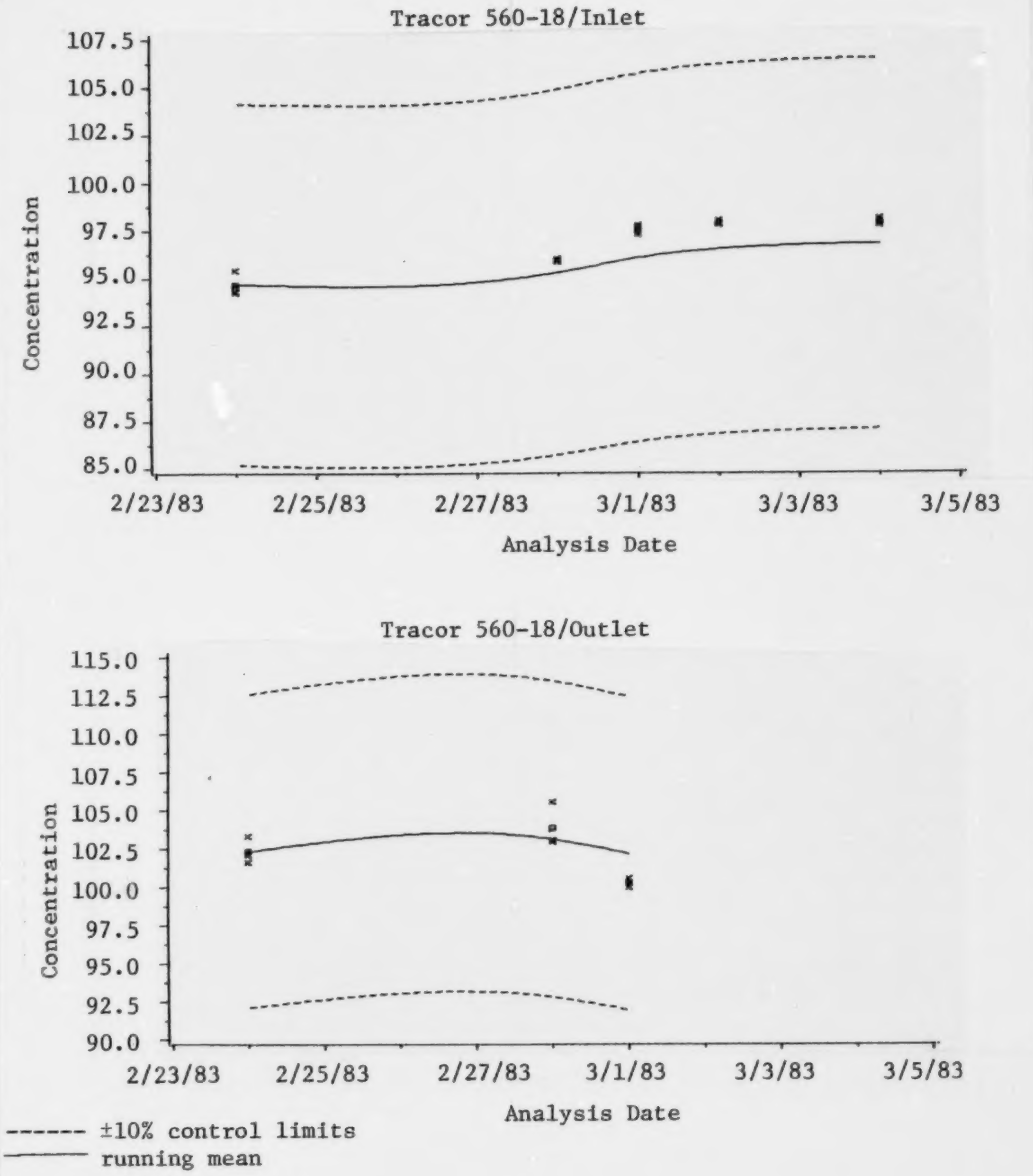


Figure 6-10. Method 18 Control Sample Data for Site C-6

TABLE 6-12. SITE C-1 - VARIABILITY OF RESULTS FOR REPLICATE[a] SAMPLES BY METHOD 18

Incinerator ID	Sampling Location	Coefficient of Variation Estimates (Degrees of Freedom)									
		C_1	C_2	C_3	C_4	C_5	C_6	MIBK	Σ Other C_{6+}	C_{6+}[b]	THC
27	Inlet	22.9 (7)	3.7 (1)	NA	10.3 (7)	16.0 (7)	7.1 (7)	13.8 (3)	22.8 (7)	14.5 (7)	12.6 (7)
	Outlet	49.8 (4)	8.6 (4)	17.7 (4)	37.9 (4)	40.8 (4)	46.5 (2)	10.4 (2)	32.4 (4)	26.2 (4)	20.4 (4)
28	Inlet	25.0 (13)	13.4 (1)	NA	115 (2)	28.5 (10)	71.8[c] (10)	39.1 (6)	53.3 (12)	59.4 (13)	54.9 (13)
	Outlet	38.8 (13)	46.4[c] (11)	51.0 (6)	81.9 (2)	76.3 (4)	35.5[c] (1)	36.1[c] (6)	65.4[c] (4)	55.8 (7)	43.1 (14)

[a] Samples analyzed under a given set of incinerator operating conditions, i.e., within a given test period; variability includes temporal variability of the process.

[b] C_{6+} = MIBK + Σ other C_{6+}.

[c] The parameter was not detected (ND) in at least one of the analyses. The CV is computed using only the quantitated values, which could result in the variability being underestimated.

NA = Not Analyzed.

TABLE 6-13. SITE C-3 - VARIABILITY OF RESULTS FOR REPLICATE[a] SAMPLES BY METHOD 18

Incinerator ID	Sampling Location	Coefficient of Variation Estimates (Degrees of Freedom)											
		1	2	3	4	5	6	7	8	9	10	11	THC
20	Inlet	40.3 (5)	38.5 (5)	29.2 (4)	52.5 (2)	ND	ND	ND	47.0 (1)	59.6 (4)	40.4 (1)	38.7 (5)	18.7 (5)
	Outlet	25.8 (4)	72.7 (4)	71.4 (4)	45.2 (3)	80.0 (1)	ND	ND	46.7 (1)	7.4 (1)	40.3 (1)	14.9 (1)	56.8 (4)
21	Inlet	38.8 (7)	33.3 (7)	31.8 (3)	125.0 (4)	100.0 (2)	91.3 (5)	41.7 (6)	78.4 (6)	66.8 (6)	60.6 (7)	39.8 (7)	43.7 (7)
	Outlet	9.6 (11)	14.5 (8)	61.6 (11)	38.3 (8)	ND	ND	ND	ND	91.8 (7)	92.0 (9)	64.5 (8)	62.3 (11)

[a] Samples analyzed under a given set of incinerator operating conditions, i.e., within a given test period; variability includes temporal variability of the process.

ND = Not Detected.

TABLE 6-14. SITE C-4 - VARIABILITY OF RESULTS FOR REPLICATE[a] SAMPLES BY METHOD 18

	Coefficient of Variation Estimates (Degrees of Freedom)												
	$<C_4$	C_4-C_5		C_6-C_7				C_{7+}					
Sampling Location	1	2	3	4	5	6	7	8	9	10	11	12	THC
Inlet	ND	ND	28.2	13.9	8.6	14.6	14.3	42.5	3.6	12.6	11.4	8.2	6.8
			(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9)
Outlet	54.0	26.0	ND	54.3	ND	8.7	26.2	82.1	67.4	7.6	9.1	9.1	8.5
	(7)	(7)		(1)		(7)	(7)	(2)	(3)	(1)	(1)	(1)	(8)

[a] Samples analyzed under a given set of incinerator operating conditions, i.e., within a given test period; variability includes temporal variability of the process.

ND = Not Detected.

TABLE 6-15. SITE C-5 - VARIABILITY OF RESULTS FOR REPLICATE[a] SAMPLES BY METHOD 18

	Coefficient of Variation Estimates (Degrees of Freedom)													
						C_{7+}								
Sampling Location	C_1-C_5	C_1-C_5	C_6	Xylene	1	Phenol	2	3	O-cresol	4	5	6	7	THC
Inlet	9.9 (14)	15.1 (14)	28.5 (14)	29.0 (14)	37.8 (14)	3.2 (14)	4.0 (14)	8.0 (14)	15.0 (14)	12.9 (14)	14.2 (14)	16.4 (14)	14.8 (14)	5.1 (14)
Outlet	11.6 (15)	56.8 (11)	42.81 (15)	26.8 (15)	15.0 (15)	14.4 (15)	30.2 (14)	88.2 (14)	18.0 (15)	12.5 (11)	23.1 (15)	18.9 (15)	19.5 (15)	10.1 (15)

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[a] Samples analyzed under a given set of incinerator operating conditions, i.e., within a given test period; variability includes temporal variability of the process.

TABLE 6-16. SITE C-6 - VARIABILITY OF RESULTS FOR REPLICATE[a] SAMPLES BY METHOD 18

Incinerator ID	Sampling Location	Coefficient of Variation Estimates (Degrees of Freedom)						
		C_1	C_2-C_3	C_4	C_5	C_6	Toluene C_{7+}	THC
	Inlet	27.6 (11)	ND	14.8 (1)	11.0 (13)	17.2 (1)	8.7 (13)	3.3 (13)
	Outlet	22.3 (14)	ND	43.5 (1)	21.1 (14)	ND	4.6 (14)	9.3 (14)

[a] Samples analyzed under a given set of incinerator operating conditions, i.e., within a given test period; variability includes temporal variability of the process.

ND = Not Detected.

for each component in each set of replicate analyses. Since the reliability of an estimate of variability is a function of the number of observations upon which the estimate is based, degrees of freedom (DF) are also presented, where DF are equal to one less than the number of observations used to calculate CV.

6.3 COMPARISON OF MEASUREMENT VARIABILITY FOR METHODS 18 AND 25A

Since Method 25A is a "semi-continuous" method, the individual measurements actually constitute replicate samples in the same sense as the Method 18 replicates. However, these number in the hundreds and a complete tabulation of this variability is not presented here. To provide a comparison of sampling/analytical variability (i.e., precision) for the two analytical methods, results obtained during selected test periods were evaluated with respect to variability. Data collected during testing at Plant C-5 were chosen for comparison since Plant C-5 data contained the largest number of comparable samples analyzed by both methods. Table 6-17 summarizes sampling/analytical variability for Method 25A and Method 18 for three test periods. Precision estimates are presented in terms of standard deviation and coefficient of variation of measured inlet and outlet THC concentrations.

As seen in the table, inlet and outlet THC precision estimates are significantly larger for Method 18. For the inlet THC data, the overall (pooled) coefficient of variation is 7.4% for Method 18, as compared to 1.2% for Method 25A. Similarly, for the outlet THC data, the overall coefficient of variation for Method 18 is 9.5%, as compared to a CV of 2.4% for Method 25A. Method 18 variability estimates for these selected test periods agree well with overall estimates of variability of Method 18 results for replicate samples at Site C-5, as presented in Table 6-15, indicating that the test periods selected are representative of typical precision for THC data. Method 25A uses flame ionization detection (FID) to provide total hydrocarbon (THC) concentrations. Similarly, Method 18 also uses an FID for quantitation, but the various organic species in the gas sample are chromatographically

TABLE 6-17. COMPARISON OF METHOD 25A AND METHOD 18 VARIABILITY ESTIMATES (PLANT C-5)

		Inlet THC Concentration				Outlet THC Concentration			
Catalyst Outlet Temperature (°C)	Analytical Method	# of Obs.	Mean (ppmv-C)	Std. Dev. (ppmv-C)	CV (%)	# of Obs.	Mean (ppmv-C)	Std. Dev. (ppmv-C)	CV (%)
482	18	8	9194	675	7.3	6	1940	175	9.0
	25A	12	8141	64	0.8	117	1669	39	2.3
554	18	8	9167	675	7.4	7	1430	148	10.3
	25A	40	8529	134	1.6	361	1501	42	2.8
577	18	8	9162	675	7.4	7	1530	138	9.0
	25A	80	8561	88	1.0	638	1541	34	2.2
	18	(pooled variability estimates)		675	7.4			153	9.5
	25A			103	1.2			37	2.4

separated prior to detection and quantitation. THC values for Method 18 analyses thus represent a summation of detector response to individual sample components. Sample-to-sample variability for individual components by Method 18, shown in Tables 6-12 through 6-16, is typically much larger (i.e., precision is poorer) than for THC values. At Plant C-5, for instance, pooled CVs for individual components ranged from 4.0 to 37.8 percent for inlet samples and from 11.6 to 88.2 percent for outlet samples.

For Method 18 THC data, precision for replicate process samples was significantly poorer (i.e., CVs were larger) than for replicate control sample analyses. Table 6-18 presents a comparison of Method 18, control sample replicability vs. variability for process samples collected under similar test conditions. Two factors contribute to the larger variability observed for process sample data:

- temporal variability of the process, and
- greater analytical difficulty for process samples due to the complexity (i.e., numerous components) of the sample gas streams.

Although larger CVs for process samples were also observed for Method 25A, this difference was much more pronounced for Method 18. At Site C-5, for instance, pooled CVs for Method 25A control sample replicate analyses were 0.4 and 1.2 percent at the inlet and outlet, respectively. As indicated in Table 6-17, Method 25A process sample CVs for the selected test period were 1.2 and 2.4 percent, respectively. These data indicate that sample composition had a large effect on precision of Method 18 results, but relatively little impact on precision for Method 25A analyses.

TABLE 6-18. COMPARISON OF VARIABILITY OF METHOD 18 CONTROL SAMPLE DATA AND METHOD 18 PROCESS DATA

	Control Sample Data[a] Coefficients of Variation		Process Sample Data[a] Coefficients of Variation	
Site	Inlet	Outlet	Inlet	Outlet
C-1	1.8	3.2	45.4	39.8
C-3	1.6	1.1	35.8	61.0
C-4	0.8	0.7	6.8	8.5
C-5	0.4[b]	0.4[b]	5.1	10.1
C-6	0.4	1.0	3.3	9.3

[a] THC values.

[b] Results for a single control sample used for both inlet and outlet measurements.

SECTION 7

PARAMETRIC ANALYSES OF INCINERATOR PERFORMANCE

Incinerator performance characterization efforts for this program focused heavily upon functional relationships between incinerator performance, in terms of VOC destruction efficiency, and various operating parameters. Parametric analyses were primarily based upon data collected at the last three sites and addressed the following operating parameters:

- operating temperature (Plants C-4, C-5, and C-6)
- inlet THC concentration (Plant C-4)
- catalyst age (Plant C-5)
- inlet THC mass flowrate (Plant C-6)
- residence time (Plant C-6)

For comparisons between destruction efficiencies measured under different operating conditions, the objectives were:

- to ascertain whether or not there was an effect, due to the parameter of interest, and
- to define the magnitude and direction (i.e., increase or decrease) of the effect in terms of destruction efficiency.

As discussed in Section 5, the validity of conclusions based on the parametric analyses is dependent only upon random error (i.e., measurement data variability) in the individual destruction efficiency estimates.

This section presents results of parametric analyses for the last three sites taken from the interim reports, along with statistical evaluation of the results. References to significance of effects pertain to statistical significance at the 95% confidence level. The methods used in determining statistical significance are discussed in Section 4. Briefly, 95% confidence values for mean destruction efficiencies measured under various conditions are based upon variability of the VOC measurement data. If there is no overlap in confidence intervals for the mean destruction efficiencies in question, then the observed differences are statistically significant, even if the absolute magnitude of the difference is small (i.e., the effect is small).

7.1 PLANT C-4 RESULTS

The catalytic incinerator at Plant C-4, a decorative can manufacturing plant, was performance tested from January 31 through February 5, 1983. During the test period, incinerator performance was characterized for two product types of varying sizes and three operating temperatures. VOC destruction efficiencies measured for the incinerator ranged from 86.1% to 94.0%.

The effect of catalyst bed inlet temperature on incinerator destruction efficiency is shown in Table 7-1. The average VOC destruction efficiency (along with approximate 95% confidence intervals) for the three catalyst inlet temperature settings used during testing are presented. Only data with approximately the same inlet THC concentration were included in this analysis. Increasing the catalyst inlet temperature from 335°C (635°F) to 391°C (735°F) resulted in an increase of VOC destruction efficiency from 88.7% to 92.4%. As illustrated in Figure 7-1, average destruction

TABLE 7-1. EFFECT OF CATALYST BED INLET TEMPERATURE ON DESTRUCTION EFFICIENCY PLANT C-4

Date	Monitoring Period	Product	THC Concentration (ppmv-C)[a]		Catalyst Bed Temperature °C (°F)		Mean Destruction Efficiency (Approximate 95% C.I.)	Natural Gas Usage m^3/s (cfm)
			Inlet	Outlet	Inlet	Outlet		
2/3/83	1300-1911 2051-2301	B	5,944[b]	611[b]	335 (635)[b]	397 (746)[b]	88.7[b] (88.4, 89.0)	0.015 (32)
2/5/83	0159-0310 0319-0534							
2/4/83	1440-1710	B	6,060	495	368 (695)	432 (810)	91.0 (89.9, 91.8)	0.019 (40)
2/4/83 - 2/5/83	2259-0101	B	5,275	363	391 (735)	452 (845)	92.4 (91.1, 93.4)	0.020 (42)

[a] ppmv-C = parts per million by volume as carbon.

[b] Average of test results during the indicated monitoring periods.

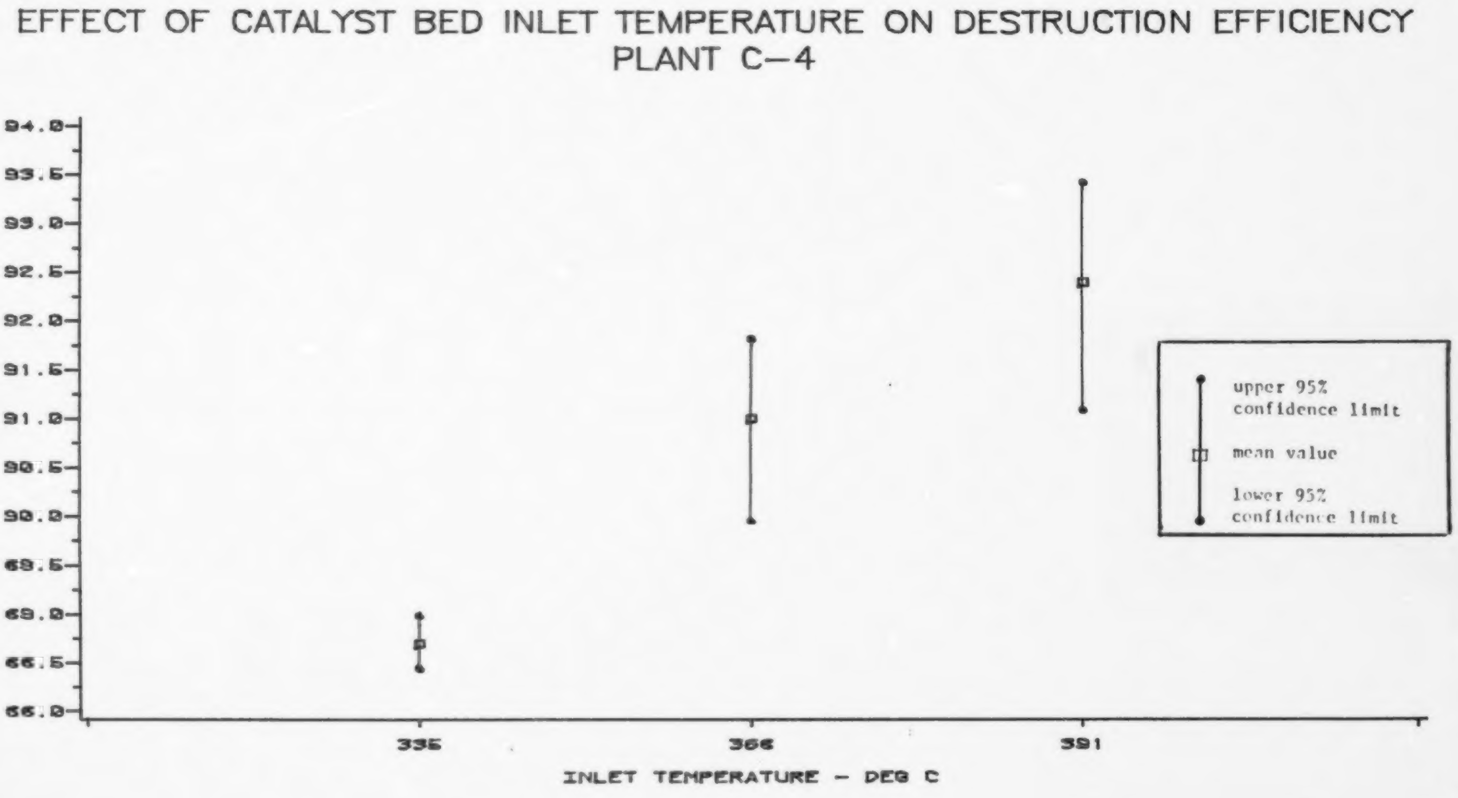
EFFECT OF CATALYST BED INLET TEMPERATURE ON DESTRUCTION EFFICIENCY
PLANT C—4

Figure 7-1. Effect of catalyst bed inlet temperature on destruction efficiency Plant C-4

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efficiencies are significantly different for the inlet temperatures of 335°C versus 368°C and 335°C versus 391°C. Note on the plot that the 95% confidence intervals on mean destruction efficiency do not overlap for those pairs of temperature levels. The linear relationship between catalyst bed inlet temperature and average destruction efficiency appears very strong with a correlation coefficient of 0.95.

As indicated in Table 7-1, natural gas consumption is increased as the catalyst inlet temperature increases. It should also be noted from Table 7-1 that the 3.7% increase in destruction efficiency resulting from raising the catalyst inlet temperature corresponds to a 40% reduction in the outlet THC concentration from the incinerator.

Table 7-2 gives incinerator destruction efficiencies for a range of inlet THC concentrations measured at the same catalyst inlet temperature. With the exception of one monitoring period (2/4/83: 1017-1117), the destruction efficiencies were between 88% and 89% regardless of inlet THC concentrations. Figure 7-2 graphically presents the mean destruction efficiencies (with 95% confidence limits) for each level of inlet THC concentration. It appears that for the relatively narrow range of inlet concentrations measured at Plant C-4, the VOC destruction efficiency remains constant, since observed differences in destruction efficiency are not statistically significant.

The average destruction efficiencies with approximate 95% confidence intervals for various VOC components are summarized in Table 7-3 according to product and catalyst inlet temperature. VOC destruction efficiencies for individual components were based on inlet and outlet mass flowrates determined from Method 18 results and average inlet and outlet gas flowrates. Also included in Table 7-3 are destruction efficiencies for THC as determined by Method 18 analyses.

As seen in Figure 7-3, although the mean destruction efficiencies for individual VOC components in Product B (inlet temperatures of 335°C, 360°C,

TABLE 7-2. EFFECT OF INLET THC CONCENTRATION ON DESTRUCTION EFFICIENCY PLANT C-4

Date	Monitoring Period	Product	THC Concentration (ppmv-C)[a]		Catalyst Bed Temperature °C (°F)		Mean Destruction Efficiency (Approximate 95% C.I.)
			Inlet	Outlet	Inlet	Outlet	
2/5/83	0608-1113	B	4,714	501	332 (630)	388 (730)	88.3 (87.4, 89.1)
2/4/83	1017-1117	B	4,725	546	332 (630)	385 (725)	87.3 (86.2, 88.2)
2/3/83	2051-2301	B	5,484	564	335 (635)	385 (725)	88.7 (87.8, 89.5)
2/5/83	0159-0310	B	5,618	592	335 (635)	407 (765)	88.4 (87.3, 89.4)
2/3/83	1300-1911	B	5,998	601	335 (635)	396 (745)	88.9 (88.5, 89.2)
2/5/83	0319-0534	B	6,418	687	335 (635)	407 (765)	88.2 (87.6, 88.8)

[a] ppmv-C = parts per million by volume as carbon.

TABLE 7-3. DESTRUCTION EFFICIENCY OF VOC COMPONENTS - PLANT C-4

		Catalyst Bed Temperature °C (°F)	Mean Destruction Efficiency[a] (Approximate 95% Confidence Interval)				
Date	Product ID	Inlet/Outlet	MIBK	Toluene	Ethyl Benzene	Xylene	THC
1/3/83 - 2/1/83	A	318 (605)/371 (700)	88.8 (73.7, 100)	-[b]	93.2 (91.3, 95.0)	96.0 (95.0, 96.9)	95.6 (95.2, 96.0)
2/3/83	B	335 (635)/396 (745)	84.1 (79.6, 88.5)	87.4 (75.0, 97.6)	-[c]	-[c]	89.4 (86.1, 92.5)
2/4/83	B	360 (680)/438 (820)	87.2 (78.5, 91.1)	90.3 (79.3, 94.2)	-[c]	-[c]	92.3 (86.3, 94.8)
2/4/83	B	391 (735)/452 (845)	89.3 (87.1, 91.1)	92.7 (90.8, 94.4)	-[c]	-[c]	93.6 (92.3, 94.7)

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[a] Based on inlet and outlet mass flowrates unless otherwise indicated.

[b] Toluene component not detected in Product A.

[c] Outlet concentration was below detection limit of 3.0 ppmv-C.

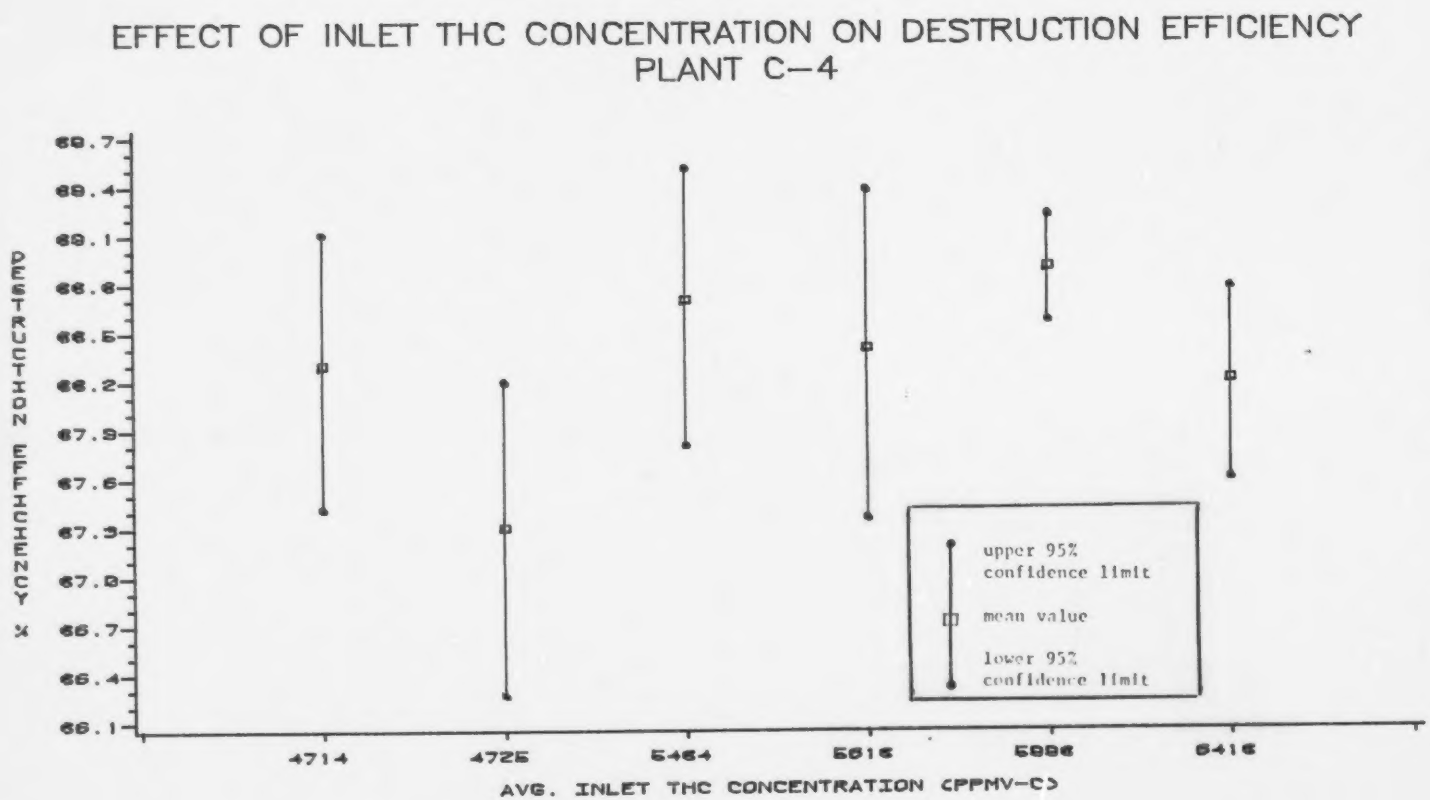

Figure 7-2. Effect of inlet THC concentration on destruction efficiency Plant C-4

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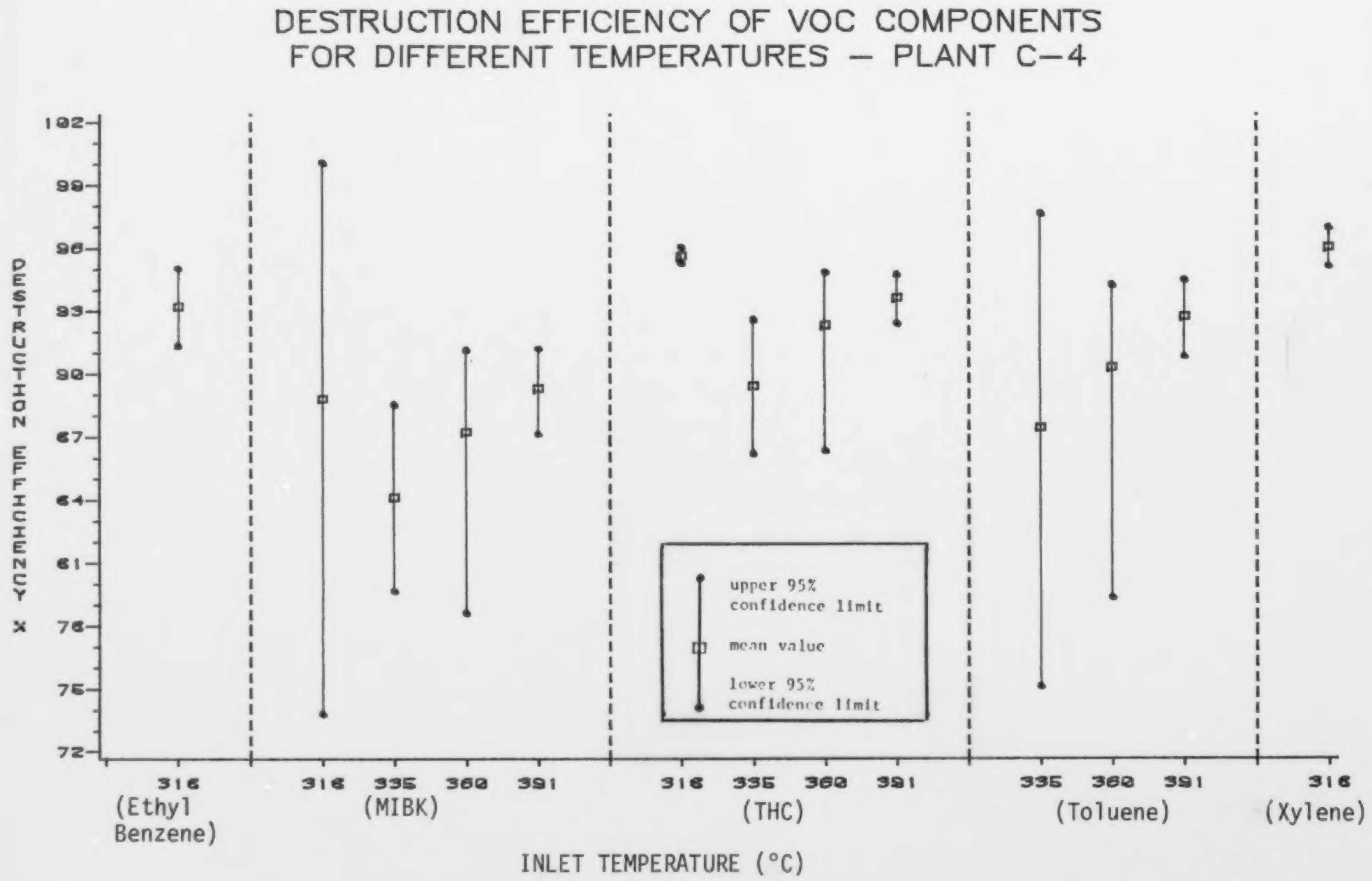

Figure 7-3. Destruction efficiency of VOC components for different temperatures
Plant C-4

and 391°C) increase as the catalyst inlet temperature increases, the mean destruction efficiencies for each temperature level are not significantly different from one another. The uncertainty seen for the destruction efficiency estimates is due to the large variability in the Method 18 data and the small number of samples taken.

7.2 PLANT C-5 RESULTS

The catalytic incinerator at Plant C-5, a magnet wire plant, was tested from February 15 through February 19, 1983. During the one-week test period, incinerator performance was characterized for a single wire product at four catalyst bed outlet temperatures and two inlet solvent concentrations. Data were also collected during incinerator operation with an old and a rejuvenated catalyst. VOC destruction efficiency varied over a relatively wide range (65.1% to 83.5%) for the conditions tested. Major factors affecting the efficiencies were operating temperature, catalyst age, and inlet THC concentrations. The lowest destruction efficiency was obtained when the inlet concentration dropped to 4638 ppmv-C and the catalyst outlet temperature was 457°C (855°F). The highest destruction efficiency was measured when the inlet concentration was 8862 ppmv-C and the catalyst outlet temperature was 544°C (1030°F).

The Plant C-5 incinerator typically operates at an incinerator outlet temperature of 482°C (900°F). During the testing period, the catalyst outlet temperature was varied from 454°C to 577°C (850°F to 1070°F). This was done to observe the effect of incinerator operating temperature on destruction efficiency. These results are shown in Table 7-4. All of the data summarized in this table were taken from steady-state monitoring periods.

Table 7-4 shows that using the new catalyst there is a general trend of increasing destruction efficiency with increasing catalyst outlet temperature. The efficiency increased from 79.5% at 482°C (900°F) to 82.4% at 554°C (1030°F). At the highest temperature (577°C, 1070°F), there is a

TABLE 7-4. EFFECT OF CATALYST AGE AND CATALYST OUTLET TEMPERATURE ON EFFICIENCY AT PLANT C-5

Date	Start Time	Catalyst Outlet Temperature °C (°F)	Average Inlet THC Concentration[a]	Average Outlet THC Concentration[a]	Mean Destruction Efficiency (%) (Approximate 95% C.I.)	Catalyst Condition	Outlet CH_4 Concentration[a]
2/18/83-2/19/83	2213	482 (900)	8645	1669	79.5 (79.4, 79.6)	New[b]	35
2/15/83-2/16/83	2007[c]	499 (930)	8868	2240	73.2 (73.1, 73.3)	Old	83
2/16/83-2/17/83	1931	507 (945)	8667	1600	80.4 (80.3, 80.5)	New	37
2/18/83	1244	554 (1030)	9070	1501	82.4 (82.3, 82.5)	New	90[d]
2/17/83-2/18/83	1808	577 (1070)	9021	1529	82.0 (81.9, 82.1)	New	262

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[a] As parts per million by volume-carbon.

[b] The new catalyst was actually another batch that had been rejuvenated.

[c] Second monitoring period began 2/16 at 08:04.

[d] Methane concentration is an approximate value obtained from the Method 18 analyses.

slight reduction in destruction efficiency to 82.0 percent. The lower efficiency is due to the relatively high concentration of methane in the outlet gas at the higher temperature, 262 ppmv methane at 577°C (1070°F) compared to 90 ppm at 554°C (1030°F). Figure 7-4 compares the mean destruction efficiencies (with approximate 95% confidence intervals) for the outlet temperature levels of 482°C, 507°C, and 554°C. The linear relationship between catalyst bed outlet temperature and average destruction efficiency is very strong with a correlation coefficient of 0.99. This plot does not include the data for which the outlet methane concentration was 262 ppmv.

The results of VOC monitoring using an old and a rejuvenated catalyst are also given in Table 7-4. Data for the old catalyst show a destruction efficiency of 73.2% (with an upper 95% confidence limit of 73.3%). During a comparable testing period using the new catalyst, a destruction efficiency of 80.4% (with a lower 95% confidence limit of 80.3%) was achieved. The lower destruction efficiency measured for the old catalyst is due to (a) lower catalyst activity caused by age or high temperature operation, and (b) leakage of SLA past the catalyst bed. Leakage occurred because the asbestos gasket used to join the catalyst modules together was missing. Since the confidence intervals for these destruction efficiencies do not overlap, the observed difference is statistically significant.

The effect of inlet concentration on destruction efficiency is shown in Table 7-5. For an increase in the inlet THC concentration from 4900 to 8600 ppmv-C, the destruction efficiency increased from 72.3% to 79.5%. A catalyst bed outlet temperature increase was also observed for the higher inlet concentration. In order to determine whether or not the reaction rate increase is due solely to temperature increase or if the increased solvent concentration also contributes by aiding the mass transfer of solvent to the catalyst surface, the effect of temperature increase was removed as follows. From the strong linear relationship between catalyst bed outlet temperature and average destruction efficiency (at average inlet THC concentrations ranging from 8645 ppmv-C to 9070 ppmv-C), an average destruction efficiency

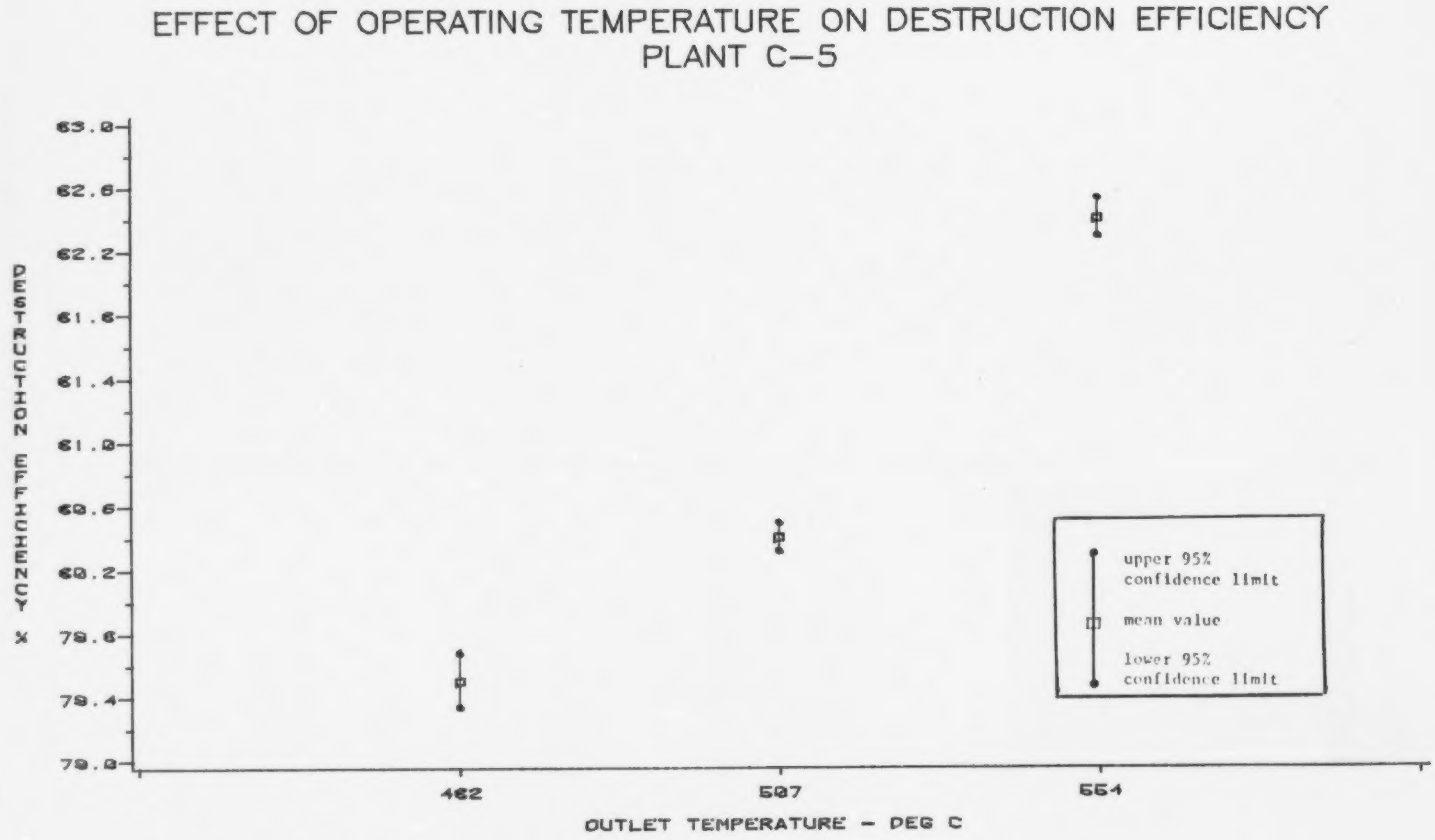

Figure 7-4. Effect of operating temperature on destruction efficiency
Plant C-5

TABLE 7-5. EFFECT OF INLET CONCENTRATION ON DESTRUCTION EFFICIENCY

		Catalyst Temperatures				
Date	Start	Inlet °C (°F)	Outlet °C (°F)	Temperature Rise °C (°F)	Average Inlet THC Concentration	Mean Destruction Efficiency (%) (Approximate 95% C.I.)
2/19/83	0041	416 (780)	454 (850)	38.9 (70)	4907	72.3 (69.6, 74.5)
2/18/83 - 2/19/83	2213	402 (755)	402 (900)	80.6 (145)	8645	79.5 (79.4, 79.6)

estimate was computed (with 95% confidence limits) for an outlet temperature of 454°C. This estimate, 78.3 with a 95% confidence interval of (78.2, 78.5), was then compared to the average destruction efficiency of 72.3 (69.6, 74.5) at an outlet temperature of 454°C and a low average inlet THC concentration of 4907 ppmv-C. The increase in efficiency at the higher inlet concentration results from an increase in the overall reaction rate of solvent and oxygen in the gas stream.

Destruction efficiencies (with approximate 95% confidence intervals) calculated for each identified VOC component in the inlet and outlet gas are presented in Table 7-6. Data from Table 7-6 and Figure 7-5 (data taken during unstable incinerator temperature is not included in the figure) show that the destruction efficiency of phenol significantly increases with increasing temperature. The trend is not quite as well defined for some of the other compounds or for THC, but in general, the destruction efficiency increases as temperature increases. With the exception of benzene, increases in mean destruction efficiency are statistically significant as catalyst outlet temperature increases from 482°C to 554°C. One reason that this trend is not better defined may be that the separation of the compounds being analyzed was not ideal; however, this was the best resolution achievable using the instrumentation and methods available.

Figure 7-5 additionally illustrates the difference in average incinerator efficiency for the four VOC components. Destruction efficiency is significantly lower for benzene (with averages ranging from 16.4% to 47.0%) than for the other identified components, while incinerator efficiency is significantly higher for o-cresol (with averages ranging from 98.1% to 99.3%).

7.3 PLANT C-6 RESULTS

The catalytic incinerator at Plant C-6, an aluminum foil coating plant, was tested from February 25 through March 4, 1983. Data collected on the

TABLE 7-6. DESTRUCTION EFFICIENCIES OF VOC COMPONENTS - PLANT C-5

Date	Catalyst Outlet Temperature (°F)	Destruction Efficiency (Approximate 95% Confidence Interval)				
		Benzene	Xylene	Phenol	o-Cresol	THC
2/18/83 - 2/19/83	900/890	16.4 (0, 41.5)	52.3 (44.1, 60.1)	76.7 (74.3, 78.9)	98.9 (98.7, 99.1)	78.9 (76.9, 80.8)
2/18/83	1020/1030	32.8 (0, 60.2)	82.4 (78.4, 86.2)	82.3 (80.4, 84.2)	99.3 (99.0, 99.6)	84.4 (82.9, 85.8)
2/17/83 - 2/18/83	1055/1070	47.0 (14.9, 68.1)	80.8 (78.8, 82.7)	87.0 (85.7, 88.2)	98.1 (96.1, 99.9)	83.3 (81.8, 84.7)
2/17/83[a]	1030	53.0 (32.2, 66.7)	87.4 (83.8, 90.2)	86.5 (79.8, 92.9)	99.6 (98.1, 100)	83.8 (77.6, 89.5)

[a] Data taken during unstable incinerator temperature.

[b] Compound merged with previous compound.

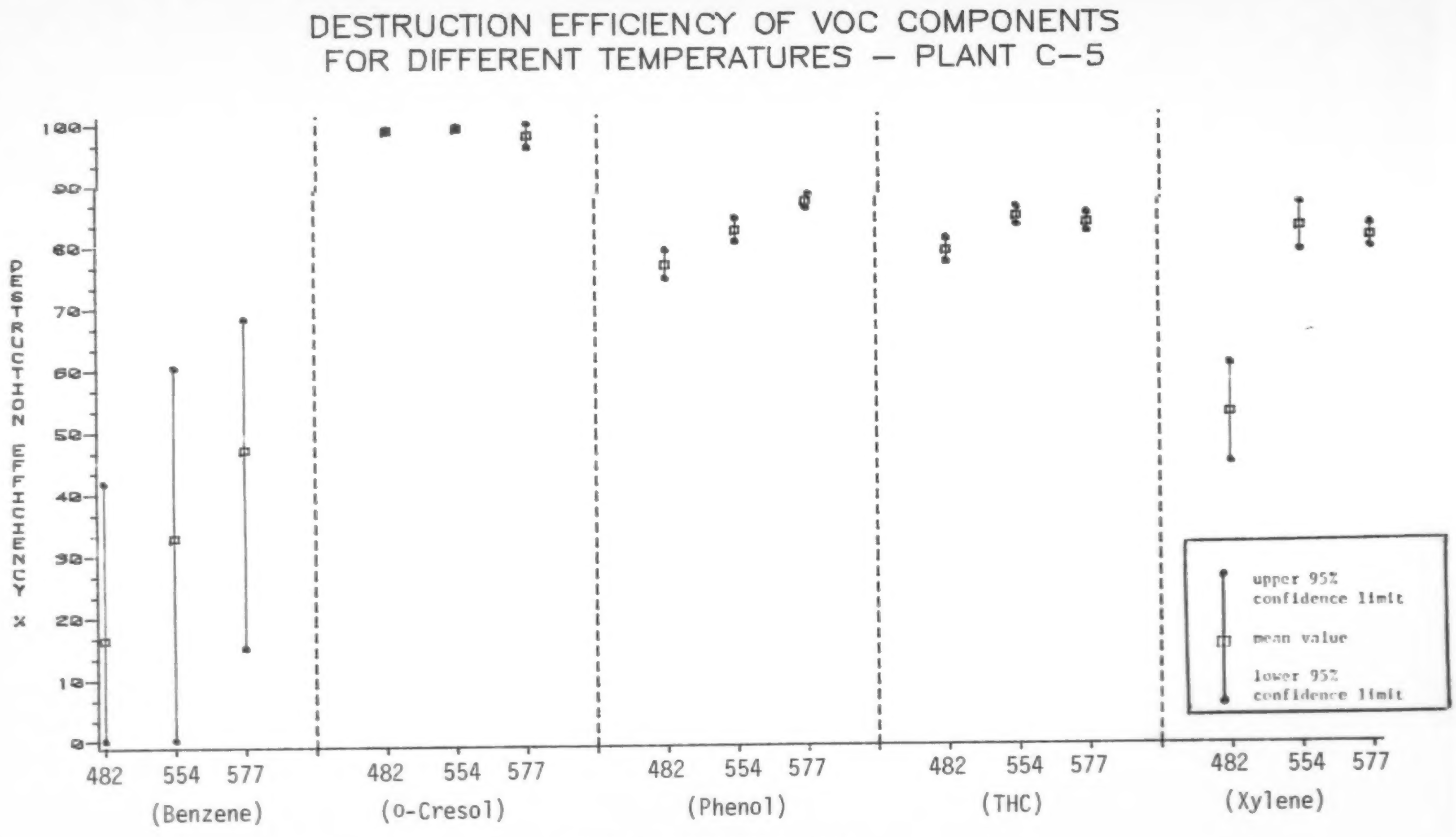

Figure 7-5. Effect of operating temperature on destruction efficiency Plant C-5

incinerator showed a narrow range of destruction efficiencies, 95.3% to 97.8%, over a fairly wide range of operating conditions. During the ten-day test period, incinerator performance was characterized for six different products, a wide range of inlet solvent mass flowrates, two operating temperatures, and two solvent-laden air residence times. Incinerator operating temperature and inlet total hydrocarbon (THC) mass flowrate were the major parameters affecting performance. Limited data suggest that solvent-laden air (SLA) residence time is also an important operating parameter. The lowest efficiencies were measured for Product D at catalyst bed inlet temperatures of approximately 254°C (490°F). The highest efficiencies were for Product B at a catalyst inlet temperature of 338°C (640°F).

The effect of catalyst inlet temperature on the VOC destruction efficiency is shown in Table 7-7 for different products at relatively constant inlet THC mass flowrates. As illustrated in Figure 7-6, increasing the catalyst inlet temperature caused a slight, but significant, increase in the destruction efficiency for all cases.

Typical relationships for destruction efficiency versus inlet temperature show gradual increases in efficiency with temperature as the efficiency approaches 100 percent (6). Small increases in efficiency with temperature would be expected for Plant C-6 because the destruction efficiencies are relatively high.

The effect of inlet THC mass flowrate on destruction efficiency is shown in Tables 7-8 and 7-9. Data for different products with similar catalyst inlet temperatures are shown in Table 7-8 and data for Product B at two catalyst inlet temperatures are shown in Table 7-9. Mean destruction efficiencies, with 95% confidence intervals, are shown in Figures 7-7 and 7-8, respectively.

The data in Tables 7-7 and 7-9 show a significant trend of increasing destruction efficiency with increasing THC mass flowrate. This trend is

TABLE 7-7. COMPARISON OF CATALYST INLET TEMPERATURE VS. DESTRUCTION EFFICIENCY PLANT C-6

Date	Time	Product	Incinerator Inlet THC Mass Flowrate kg/hr (lb/hr)	Catalyst Inlet Temperature °C (°F)	Outlet THC Concentration ppmv-C	Destruction Efficiency (%) (Approximate 95% C.I.)
3/2/83	0438-0638	B	89.8 (198)	282 (540)	280	97.0 (96.9, 97.1)
3/2/83	1232-1402		89.4 (197)	341 (645)	218	97.6 (97.5, 97.7)
3/4/83	0540-0755	B	81.7 (180)	285 (545)	295	96.5 (96.4, 96.6)
3/3/83	2015-0003		78.0 (172)	341 (645)	245	97.0 (96.9, 97.1)
3/3/83	0932-1104	D	58.1 (128)	252 (485)	269	95.5 (95.2, 95.8)
3/3/83	1556-1711		58.5 (129)	288 (550)	248	95.9 (95.8, 96.0)
3/4/83	1732-2021	E	98.4 (217)	277 (530)	279	97.3 (97.2, 97.4)
3/4/83	2127-2209		97.1 (214)	307 (585)	250	97.5 (97.4, 97.6)

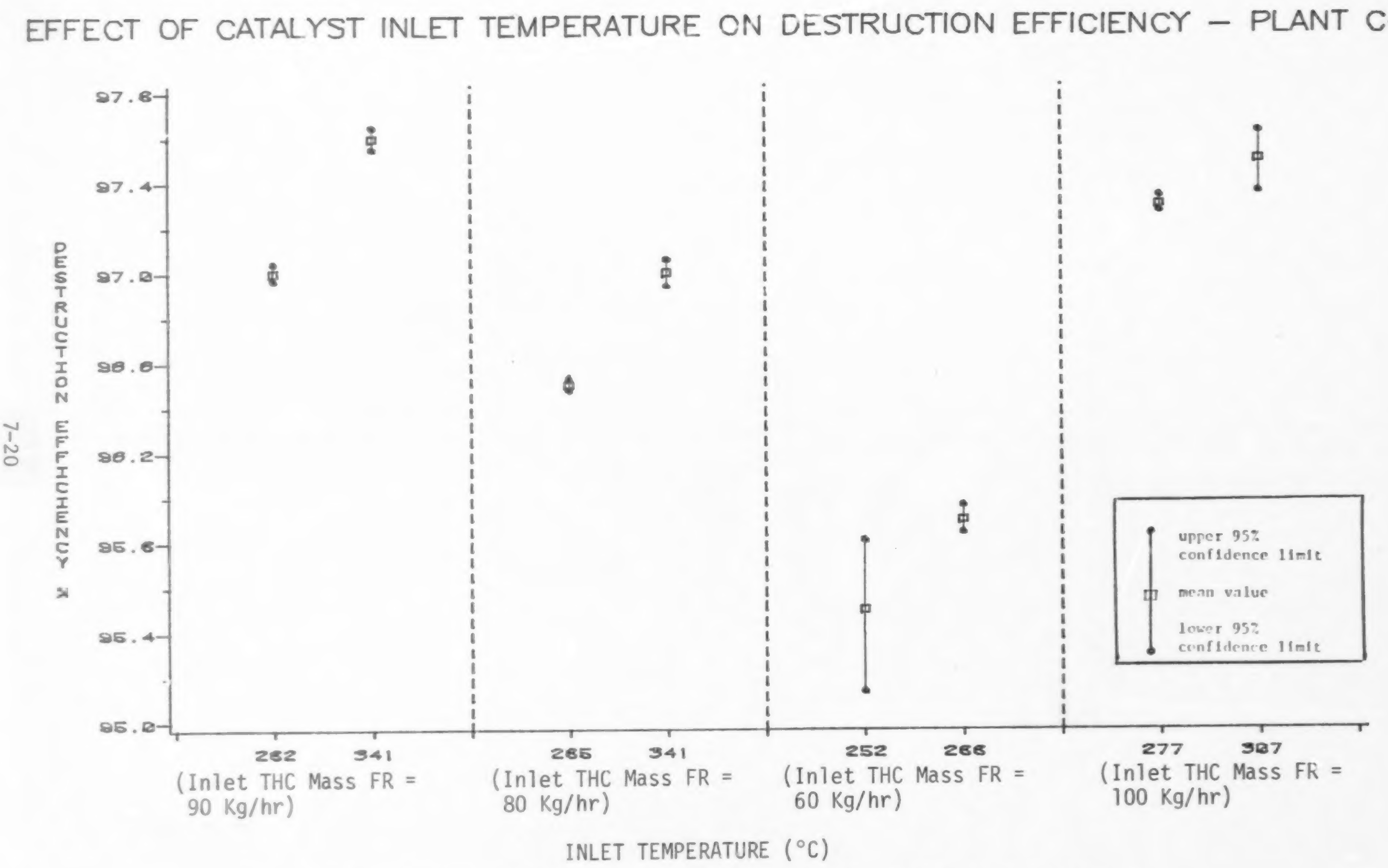

Figure 7-6. Effect of catalyst inlet temperature on destruction efficiency
Plant C-6

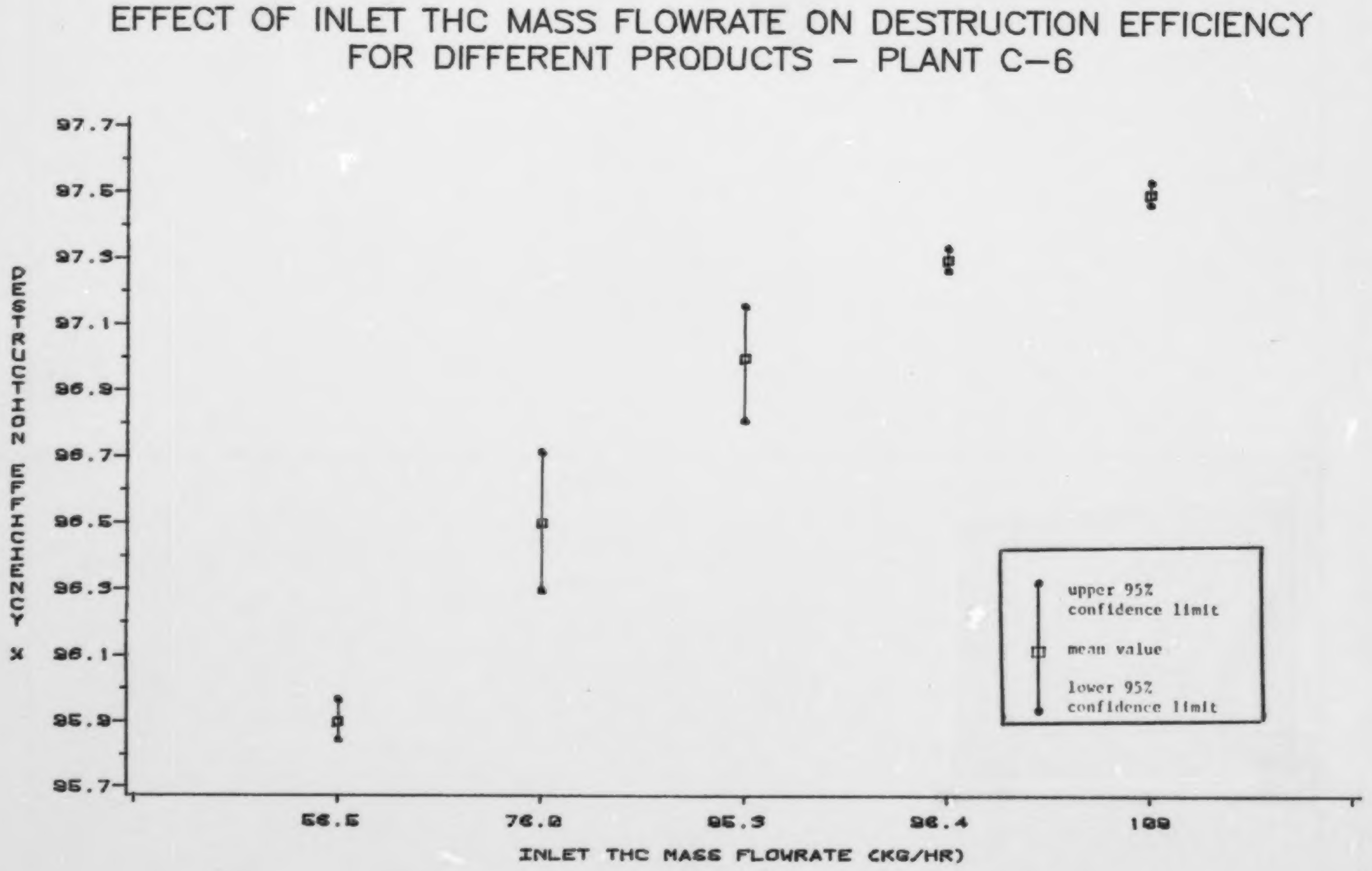

Figure 7-7. Effect of inlet THC mass flowrate on destruction efficiency for different products - Plant C-6

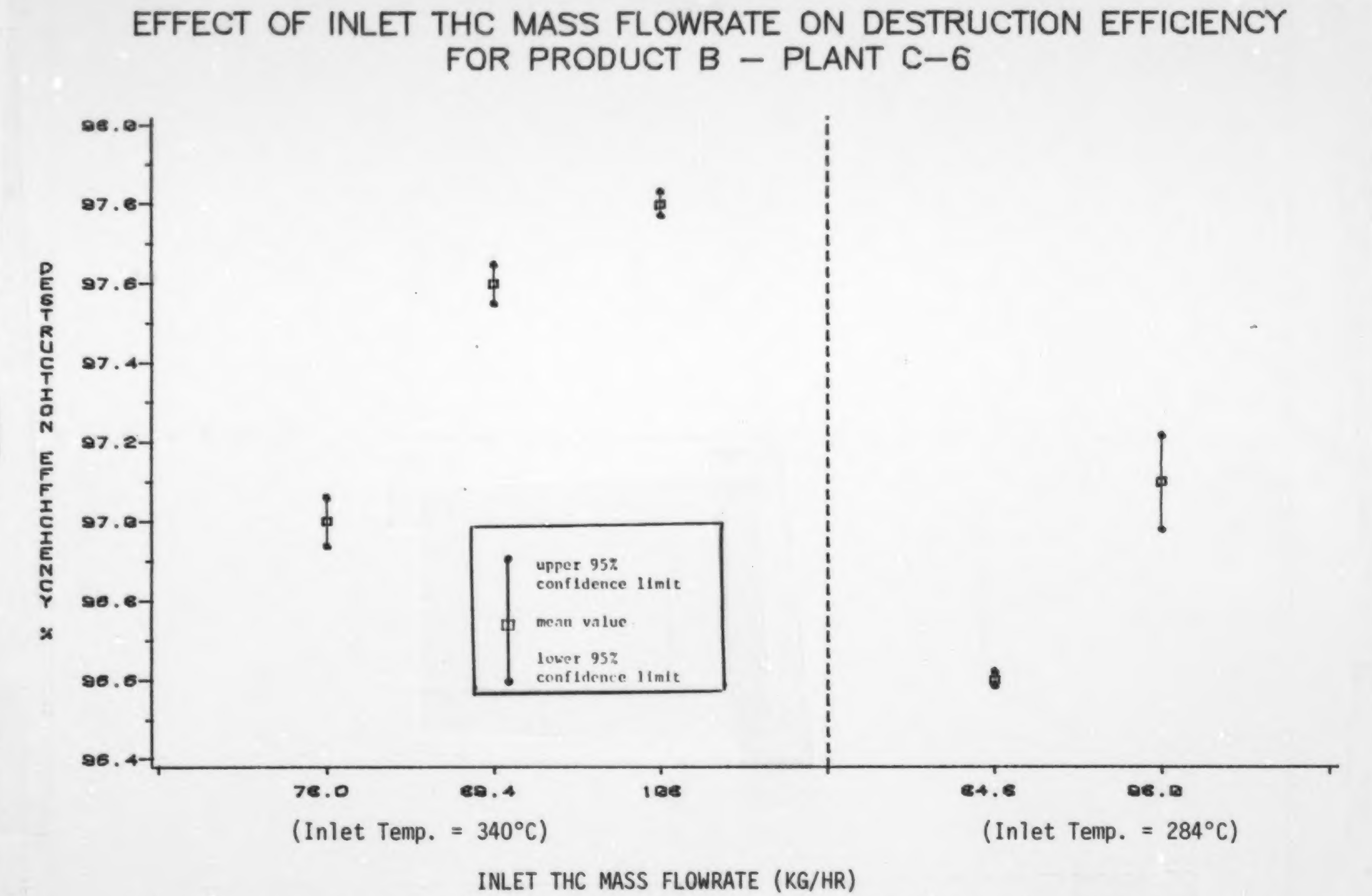

Figure 7-8. Effect of inlet THC mass flowrate on destruction efficiency for Product B Plant C-6

illustrated in Figures 7-7 and 7-8. The linear relationship between inlet THC mass flowrate and average destruction efficiency, as seen in Figure 7-7, is very strong with a correlation coefficient of 0.99. At a catalyst inlet temperature of approximately 285°C (545°F), the destruction efficiency increased from 95.9% to 97.5% as the inlet THC mass flowrate increased from 58.5 to 109 kg/hr (129 to 241 lb/hr).

The increase in destruction efficiency with increasing inlet THC mass flowrate results from an increase in the overall reaction rate between the solvent and oxygen in the gas stream. The increase in the overall reaction rate results from either an increase in the chemical reaction rate for the solvent and oxygen on the catalyst surface or the rate of mass transfer of solvent to the catalyst surface (7).

Due to the short service life of the catalyst tested at Plant C-6, it is likely that the catalyst is still highly active and that the overall reaction is not chemical (surface) reaction rate limited. If the overall reaction is solvent mass transfer limited, then increased inlet THC concentration would be expected to increase the overall reaction rate. The higher concentration of solvent in the bulk gas would aid mass transfer by creating a greater driving force for the solvent to migrate to the catalyst surface.

The effect of SLA residence time is shown in Table 7-10 for Products B, C, and F at similar inlet THC mass flowrates and catalyst inlet temperatures. The data for Products C and F should be directly comparable because solvents in both of these products consist of 100% methyl ethyl ketone (MEK). Product B was the only product tested at both residence times. The SLA residence time was longer for two monitoring periods because the inlet SLA thermocouple was out of the inlet duct.

As illustrated in Figure 7-9, destruction efficiency increases with increasing catalyst bed residence time. The significant increase in

TABLE 7-8. EFFECT OF INLET THC MASS FLOWRATE ON DESTRUCTION EFFICIENCY FOR DIFFERENT PRODUCTS - PLANT C-6

Date	Time	Product ID	Inlet THC Mass Flowrate kg/hr (lb/hr)	Destruction Efficiency (%) (Approximate 95% C.I.)	Catalyst Inlet Temperature °C (°F)	Catalyst Outlet Temperature °C (°F)
3/3/83	1556-1711	D	58.5 (129)	95.9 (95.8, 96.0)	285 (545)	374 (705)
3/2/83	1937-2121	C	78.0 (172)	96.5 (96.3, 96.7)	276 (530)	424 (795)
2/28/83	1406-1737	B	95.3 (210)	97.0 (96.8, 97.1)	285 (545)	418 (785)
3/4/83	1732-2021	E	98.4 (217)	97.3 (97.2, 97.4)	276 (530)	435 (815)
3/1/83 - 3/2/83	1711-0203	A	109 (241)	97.5 (97.4, 97.6)	285 (545)	441 (825)

TABLE 7-9. EFFECT OF INLET THC MASS FLOWRATE ON DESTRUCTION EFFICIENCY FOR PRODUCT B AT TWO CATALYST INLET TEMPERATURES - PLANT C-6

Date	Time	Product ID	Incinerator Inlet THC Mass Flowrate kg/hr (lb/hr)	Destruction Efficiency (%) (Approximate 95% C.I.)	Average Gas Temperature	
					Catalyst Inlet °C (°F)	Catalyst Outlet °C (°F)
3/3/83	2015-0013	B	78.0 (172)	97.0 (96.9, 97.1)	341 (645)	443 (830)
3/2/83	1232-1402	B	89.4 (197)	97.6 (97.5, 97.7)	341 (645)	457 (855)
3/2/83	0933-1114	B	108 (230)	97.8 (97.7, 97.9)	338 (640)	474 (885)
3/4/83	0051-0755	B	84.8 (187)	96.6 (96.5, 96.7)	285 (545)	407 (765)
2/28/83	0725-1737	B	98.0 (216)	97.1 (97.0, 97.2)	282 (540)	416 (780)

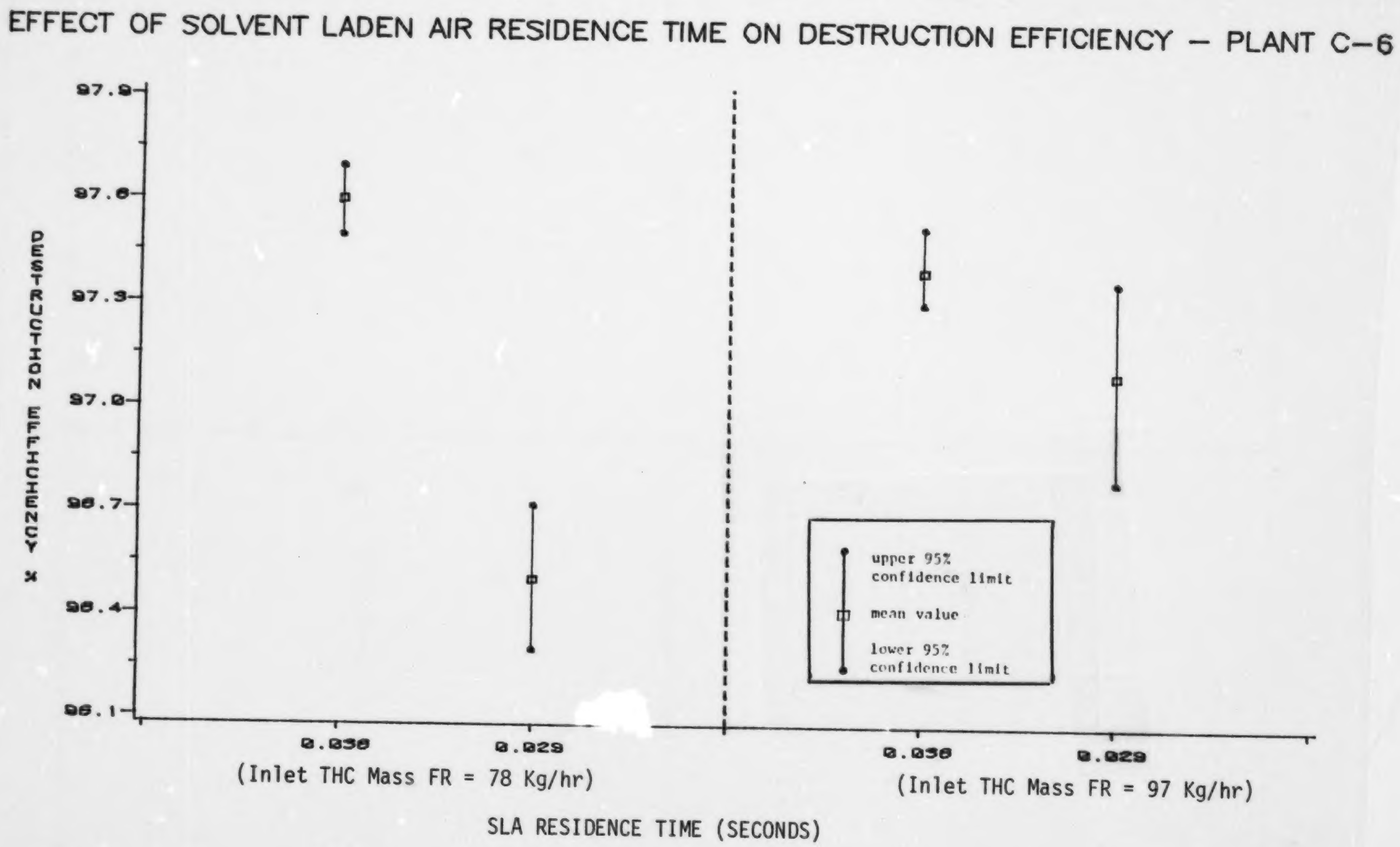

Figure 7-9. Effect of solvent laden air residence time on destruction efficiency Plant C-6

efficiency for Product F compared to Product C is 1.1% at an inlet THC mass flowrate of 78.0 kg/hr (172 lb/hr). A portion of this increase is probably due to the slightly higher catalyst bed inlet temperature for Product F. For Product B, the measured increase in efficiency (0.3%) is not statistically significant at a higher inlet THC mass flowrate of approximately 97.2 kg/hr (214 lb/hr).

Due to the limited amount of data in Table 7-10, no conclusions can be made on whether the smaller increase in destruction efficiency for Product B is the result of the toluene in Product B or the higher inlet THC mass flowrate. Product B solvents consist of an approximately 50/50% by weight mixture of MEK and toluene and the solvent for Products F and C is 100% MEK.

Higher destruction efficiencies are expected for longer residence times because more catalyst surface area is available per unit volume of gas passing through the incinerator. In addition, the effect of SLA residence time is expected to decrease as the destruction efficiency approaches 100% (6).

Destruction efficiencies (with approximate 95% confidence intervals) for MEK, toluene, and THC for Products A, B, D, and E are presented in Table 7-11. The table shows an average destruction efficiency of 96.4% for toluene. As shown in Figure 7-10, toluene destruction efficiency is relatively constant for toluene inlet concentrations ranging from 1780 to 4880 ppmv-C and catalyst outlet temperatures ranging from 374°C (705°F) to 443°C (830°F). Destruction efficiencies for MEK vary from 92.8% with Product D to 97.1% with Products A and B. The lower MEK destruction efficiencies for Products D and E may be a result of lower MEK inlet concentrations, approximately 1600 ppmv compared to 2600 ppmv for Products A and B.

Destruction efficiencies of THC for Products A, B, and E averaged 96.4%. There is very little variation in the destruction efficiencies for these three products. THC destruction efficiency for Product D (94.3%) is, however, significantly lower. The lower efficiency for Product D is most likely a result of the lower inlet THC concentration.

TABLE 7-10. EFFECT OF SOLVENT LADEN AIR RESIDENCE TIME ON DESTRUCTION EFFICIENCY - PLANT C-6

Date	Time	Product ID	Inlet THC Mass Flowrate kg/hr (lb/hr)	SLA Residence Time (Seconds)	Destruction Efficiency (%) (Approximate 95% C.I.)	Outlet THC Concentration (ppmv)	Catalyst Inlet Temperature °C (°F)
2/25/83	2051-2134	B	78.0 (172)	0.036	97.6 (97.5, 97.7)	199	285 (545)
3/2/83	1937-2121	C	78.0 (172)	0.029	96.5 (96.3, 96.7)	286	274 (525)
2/28/83	0725-0811	B	98.0 (216)	0.036	97.4 (97.3, 97.5)	263	285 (545)
2/28/83	1406-1506	B	96.2 (212)	0.029	97.1 (96.8, 97.3)	291	285 (545)

TABLE 7-11. DESTRUCTION EFFICIENCIES OF MEK AND TOLUENE FOR DIFFERENT PRODUCTS AND TEMPERATURES - PLANT C-6

Date	Sample Location	Concentration (ppmv-C quantitated against propane)			Mean Destruction Efficiency (%) (Approximate 95% C.I.)			Catalyst Temperature		Product
		MEK	Toluene	THC	MEK	Toluene	THC	Inlet °C (°F)	Outlet °C (°F)	
3/1/83	Inlet	2570	4490	7070	97.1 (95.7, 98.0)	96.1 (95.0, 96.8)	96.3 (95.8, 96.7)	285 (545)	416 (780)	A
	Outlet	75.7±13.4	174±5	267±16				285 (545)	443 (830)	
3/3/83	Inlet	2610±29	3000±57	5630±36	97.1 (95.7, 98.5)	96.6 (96.2, 97.0)	96.6 (95.8, 97.4)	341 (645)	443 (830)	B
	Outlet	76.8±32.2	103±9	194±42						
3/3/83^{ab}	Inlet	1560±155	1780±213	3630±403	92.8 (90.6, 94.2)	96.3 (94.5, 97.4)	94.3 (91.9, 95.8)	288 (550)	374 (705)	D
	Outlet	113±1	65.7±3.0	208±7						
3/4/83	Inlet	1650±326	4880±424	6550±116	95.2 (92.9, 96.7)	96.7 (96.3, 97.1)	96.1 (95.9, 96.3)	277 (530)	435 (815)	E
	Outlet	79.3±15.6	161±4	257±12						

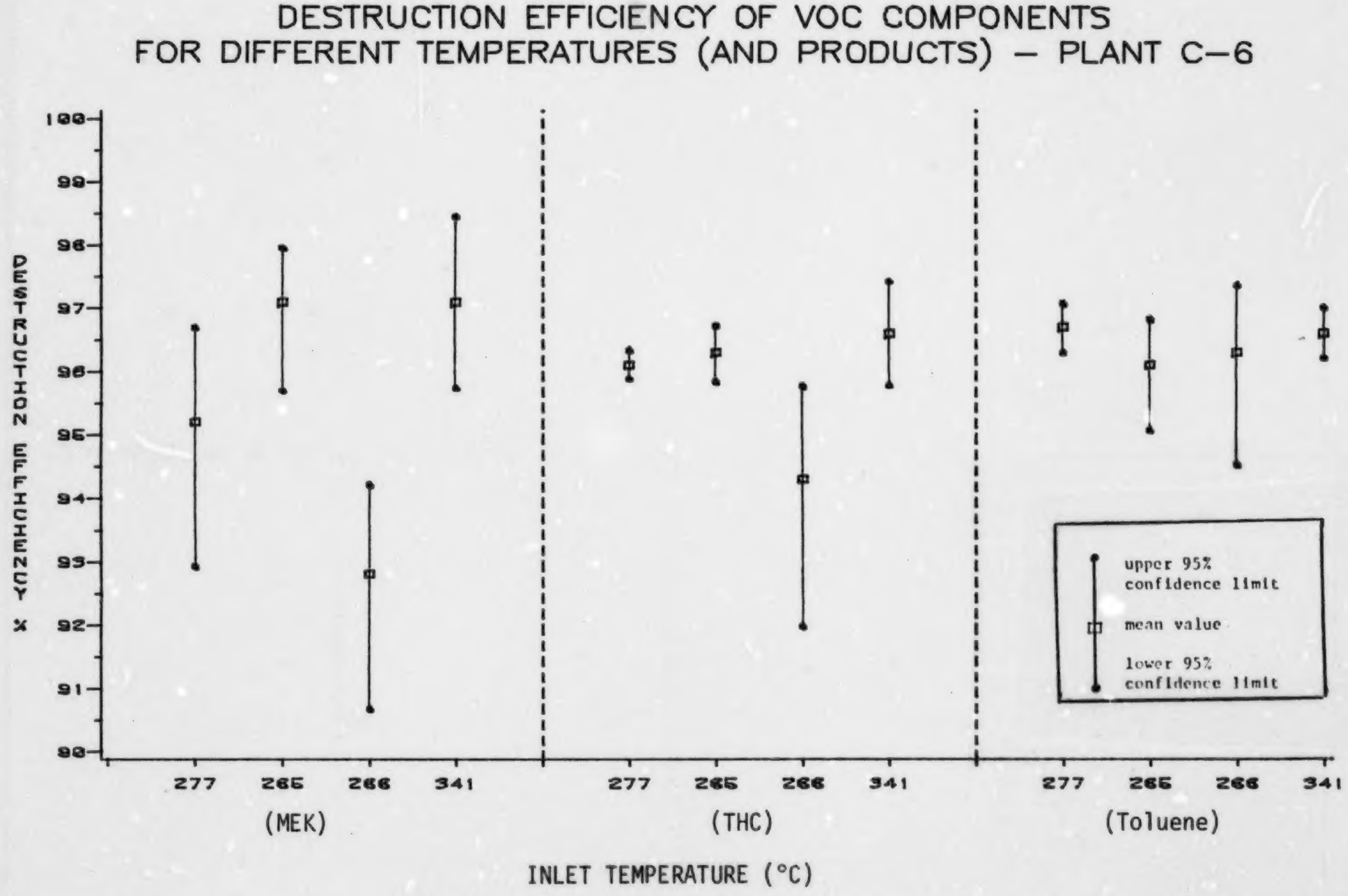

Figure 7-10. Destruction efficiency of VOC components for different temperatures (and products) - Plant C-6

SECTION 8

PROCEDURAL MODIFICATIONS

The catalytic incineration test program was basically a research-oriented testing effort. The system of test methods, procedures, instrumentation, and techniques documented in the Quality Assurance Project Plan and the Generic Test Plan were formulated prior to initiation of field testing efforts and represented the basic conceptual framework for accomplishing the program objectives. It was, however, recognized at the outset of the program that the research nature of the effort, coupled with unforeseeable site-specific considerations, would ultimately require some modifications of the testing protocol as originally defined. It was for this reason that detailed individual test plans were prepared for each site, augmenting the Generic Test Plan and the Quality Assurance Project Plan. Anticipation of the requirement for procedural modifications during the course of the project was also a primary justification for staffing each field test team with both an experienced field engineer and one or more analytical chemists, providing the on-site technical expertise to respond to special circumstances and make necessary technical judgments within the tight time constraints for testing at each site.

During the course of the field testing efforts, a number of modifications were made to the procedures originally presented in the Quality Assurance Project Plan, primarily in response to unanticipated and/or site-specific circumstances. The purpose of this section is to systematically document these modifications and to present justifications for them. Deviations from the original project organization are addressed in Section 8.1. Section 8.2 describes modifications in sampling and analytical procedures, while Section 8.3 deals with calibration procedures. Data reduction is addressed in Section 8.4. Section 8.5 summarizes the results of the data validation efforts based on acceptance criteria for analytical quality control checks specified in Section 8 of the Quality Assurance Project Plan. Most of the procedural modifications discussed in this section are also addressed in the reports prepared for each site.

8.1 PROJECT ORGANIZATION

The original project organization, as described in Section 2 of the Quality Assurance Project Plan, was developed based upon similar large-scale test programs previously conducted by Radian. Two modifications of the original project organization were made in the early phases of the project. The modifications were made in response to changing test schedules and personnel availability. These modifications involved (1) the team approach selected for the catalytic incinerator testing, and (2) key personnel assignments. These modifications are discussed in this section.

The team approach as outlined in the Quality Assurance Project Plan indicated that two discrete test teams would be separately deployed, with both teams capable of and equipped for the testing of catalytic incinerators. This approach was selected so that the program could be executed in parallel with a concurrent EPA-funded test program of thermal incinerators (EPA Contract Nos. 68-03-3038 and 68-03-3171). In this manner, both catalytic and thermal incinerators could be tested by either team, depending on the geographic location of the individual sites and the scheduling availability of the teams. The teams were equipped with essentially identical equipment and personnel with comparable backgrounds and experience.

However, the actual schedules of the catalytic and thermal incinerator test programs did not coincide as had been originally planned. The catalytic incinerator testing was conducted before the majority of the thermal incinerator testing was completed. Therefore, the availability of personnel and equipment was more flexible, allowing for one test team to complete the bulk of the catalytic incinerator testing (Sites C-1, C-4, C-5, and C-6).

Furthermore, the increased flexibility with regard to personnel availability allowed for manpower assignments to be optimized for the individual sites. The overall result of the modificiation regarding the test teams was increased consistency from site to site.

The second modification of project organization involved the changing of key personnel assignments. In particular, the responsibilities designated in the Quality Assurance Project Plan for M.S. Jennings were reassigned to M.A. Palazzolo before testing commenced. These responsibilities included the roles of Project Director and Task Leader for the site selection and final report development tasks. The personnel change was made because of limitations in Mr. Jennings' schedule and because of Mr. Palazzolo's significant level of experience in the technical evaluation of processes in the surface coating industry. The modification represented an improvement to the project organization, especially because of Mr. Palazzolo's original designation as Task Leader for the key field testing task. Assignment of the dual role of Project Director and Field Testing Task Leader to Mr. Palazzolo enabled key field decisions to be made by the person both intimately knowledgeable of the technical aspects of the project, as well as responsible for the overall technical progress of the project.

8.2 SAMPLING AND ANALYTICAL PROCEDURES

During the course of the incinerator test program, it was necessary to make a number of modifications in details of the sampling and analytical protocol described in the Quality Assurance Project Plan. Although the methods ultimately used were the same as those originally proposed (i.e., Methods 25A and 18 for VOC measurements, Methods 1 and 2 for velocity/volumetric flow rate, etc.) there were deviations from the original protocol with respect to the instrumentation which was used, the sample acquisition system, etc. These modifications were largely due to differences encountered in gas stream composition from that which was originally anticipated.

The most notable difference in analytical protocol was the different instruments used for gas phase analyses. Table 8-1 summarizes the instruments which were actually used at each site for the various measurement methods. Also included in this table is the type of samples which were collected for GC/MS analyses. The rationale for these changes is discussed in the following sections. Other modifications and details of the sampling/analytical protocol are discussed in the remainder of this section.

8.2.1 Testing Schedule

In the site-specific test plan for each incinerator, a list of daily testing activities and a corresponding test schedule was presented. As noted in the test plans, this schedule was to be used as a guideline only. Conditions existing on-site required that test procedures be flexible with regard to method and sequence.

The testing schedule outlined in the site-specific test plans was modified by the on-site task leader and test team as necessary to meet the following goals:

- to maximize Method 25A data capture;
- to fully characterize incinerator operation under at least three different sets of operating conditions;
- to organize data collection around plant operating schedules; and
- to organize data collection around sampling and analytical problems or difficulties that may have arisen.

The test schedules varied considerably at the different plants and the times during which data were collected are presented in the interim test reports. One schedule modification that was implemented at all of the sites was the elimination of a discrete two-hour "test run."

TABLE 8-1. INSTRUMENTS USED AT EACH SITE

Site No.	VOC Measurements							Fixed Gases	
	Method 25A		Methane		Method 18		GC/MS	$O_2/N_2/CO_2$	CO
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	All	All	Outlet
C-1	Byron-301	Byron-401	Byron-301	Byron-401	HP 5730A	Tracor-560	Canister	Fisher 1200	Byron-401
C-2	Tracor-560	Byron-401	NA	Byron-401	Antek-460	Antek-460	NA	Fisher-1200	Byron-401
C-3	Tracor-560	Byron-401	NA	Byron-401	Antek-460	Antek-460	Canister & Impinger	Fisher-1200	Byron-401
C-4	Byron-301	Byron-401	Byron-301	Byron-401	Tractor-560	Tracor-560	Canister	Fisher-1200	Byron-401
C-5	Tracor-560	Byron-401	NA	Byron-401	HP 5730A	HP 5730A	Impinger	Fyrite/ Byron-401	Byron-401
C-6	Byron-301	Byron-401	Byron-301	Byron-401	Tracor-560	Tracor-560	Canister	Fyrite/ Byron-401	Byron-401

NA = Not Applicable

Incinerator operating conditions changed frequently at the sites tested and a "test run" was redefined to consist of all data collected at a given set of operating conditions. In most cases, the operating condition was defined by a certain product type or product run and an incinerator operating temperature set-point.

The test runs ranged in length from 10 minutes to approximately 14 hours. Inlet and outlet VOC concentrations were monitoried with Method 25A continuously during a test run. Every effort was made to collect sufficient data to fully characterize operating conditions during the test run, provided that (1) the run was long enough, and (2) the test team was on site. For most of the incinerator configurations tested, gas flow rates and moisture contents were constant. Thus, for the short test periods, flow rates and moisture contents measured during longer test runs could be assumed.

8.2.2 VOC Measurements

This section documents differences between the VOC sampling/analytical protocols described in the Quality Assurance Project Plan and the procedures ultimately employed.

8.2.2.1 Sample Acquisition--

VOC sample acquisition followed the procedures outlined in Section 4.2.1.1 of the Quality Assurance Project Plan except for the deviations discussed below.

The calibration valve located immediately after the probe was intended to be used to introduce QC sample gas into the sample collection system. Instead of going through a valve, the QC gas line was connected directly to the rest of the sample collection system. This eliminated the possibility of any leakage due to the valve which might have caused dilution of the QC gas.

The revised Quality Assurance Project Plan contained the illustration of the sampling system as shown in Figure 8-1. The sample pump was actually placed downstream of the gas chromatographs and the Byron instruments and upstream of the Fisher during part of the testing at the first site. Attempts to use this system were based on cost and availability of pumps. Initial tests in-house at Radian showed this set-up to be difficult to use and greatly increased chances of air being drawn in and diluting the gases being analyzed. Therefore, heated pumps were purchased (∿$3,000). They arrived at the first site during testing and were placed downstream of the heated line and upstream of the instruments (similar to the arrangement shown in Figure 8-1). Table 8-2 contains the pump position at each site and rationale for moving the pump. Upon suggestion from Radian's audit personnel, the pumps were moved to their final location next to the sampling point.

The sample conditioning system described in the Quality Assurance Project Plan was never used. Since no particulate matter or high moisture was ever encountered at any of the plants tested, the sample conditioning system was not required.

The heated pump located upstream of the instrument manifold provided a high flow (5L/min) of sample gas to the instrument manifold. Most of this gas was vented before entering the manifold itself, providing a low flow of sample gas to the instruments. In the case of the Byron analyzers, gas flow was maintained at about 50 ml/min through the sample loop and was not stopped and allowed to equilibrate to atmospheric pressure before sample injection. Although the flow of sample gas could not be equilibrated to atmospheric pressure before injection, the calibration standards were also analyzed in the same manner, with the flow rate of the calibration gas corresponding to the flow rate of the sample gas. With respect to the gas chromatographs, the flow of sample gas through the sample loop was interrupted and the gas allowed to equilibrate to atmospheric pressure before injection. The calibration standards were analyzed in a like manner.

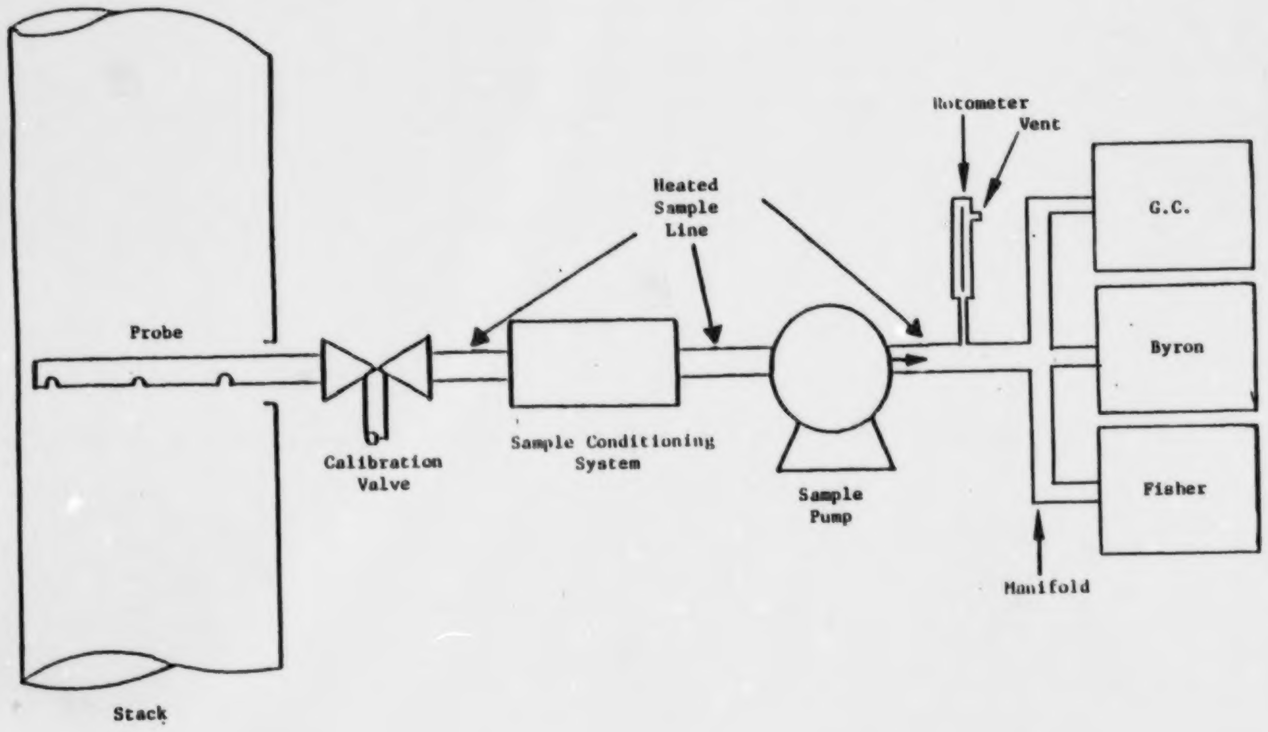
Probe
Stack
Calibration Valve
Heated Sample Line
Sample Conditioning System
Sample Pump
Rotometer
Vent
G.C.
Byron
Fisher
Manifold

Figure 8-1. Organic Concentration Measurement System

TABLE 8-2. ARRANGEMENT OF SAMPLING SYSTEM PUMP FOR EACH SITE

Site Number	Position of Pump	Rationale
C-1	Downstream of Instruments	Pump Unheated
	Upstream of Instruments	Heated Pump Obtained On-Site
C-2	Upstream of Instruments	
C-3	Upstream of Instruments	
C-4	Upstream of Heated Line	QA Report suggested change to minimize possible air leaks into system
C-5	Upstream of Heated Line	
C-6	Upstream of Heated Line	

8.2.2.2 Method 25A--Inlet Analyses--

The relatively high molecular weight (i.e., low volatility) of the inlet solvent laden air (SLA) at Plants C-2, C-3, and C-5 were incompatible with the fixed temperature of the Byron 301. Previous experience under similar circumstances indicated that a significant portion of the sample gas would condense inside the instrument and give erroneous results.

To obtain inlet total hydrocarbon (THC) data at Plants C-2, C-3, and C-5, a Tracor 560 chromatograph was modified and used in place of the originally specified Byron 301. The inlet sample injection valve was installed in the GC oven and maintained at or above the sample line temperature to prevent condensation. A value actuator with adjustable cycle timer was installed to provide semi-continuous sampling. Finally, to obtain THC data, the separation column was replaced with a piece of empty 1/16" SS tubing.

Cycle times varied from plant to plant depending on the apparent variability of VOCs in the inlet SLA. With this analytical system, separate methane concentrations were not obtained. Since inlet methane concentrations were very low at the plants where it was measured, this deficiency at Plants C-2, C-3, and C-5 should not present any serious problems in terms of overall data quality.

8.2.2.3 Method 18 Analyses--

Analysis of VOC compounds using Method 18 was accomplished according to the sampling and analytical procedures discussed in Section 4.2.2 of the Quality Assurance Project Plan, except that chromatographic conditions were different at each plant.

The Quality Assurance Project Plan presented gas chromatographic (GC) parameters designed to optimize the analysis for C_1 to C_6 hydrocarbons. After analyzing the first samples at Plant C-1, it was observed that most of the species were eluting after hexane (C_6). In order to obtain more useful information concerning the composition of the gas streams, the GC oven conditions were changed to optimize the separation and quantitation of the compounds that were present.

Since most of the other plants also used a variety of solvents heavier than C_6, it was evident that the C_1-C_6 analysis parameters would be inadequate for characterizing these gas streams. Consequently, different gas chromatographic columns and conditions were developed for each plant in order to better speciate the compounds contained in the gas streams. The GC parameters developed for each plant are contained in their respective interim reports. Table 8-3 shows the solvents used at each of the catalytic plants for which parameters were developed.

8.2.3 Molecular Weight Determination

At two of the catalytic test sites, Plants C-5 and C-6, the Fisher Model 1200 Gas Partitioner was inoperable throughout the testing. An alternate method was therefore used to determine gas molecular weight. A Fyrite® analyzer was used to measure gas oxygen content and the Byron 401 was used to measure CO_2 concentrations. Nitrogen was determined by difference.

The Fyrite® analyzer solution was checked for viability by sampling ambient air and the Byron 401 was calibrated using a single point calibration. Calibration gas for the CO_2 was a mixed gas standard containing 1.9% CO_2.

Gas molecular weights determined by the alternate method were verified by engineering judgment and comparison with molecular weights determined using the Gas Partititioner at other catalytic test sites. The use of the alternate method was not expected to have had an adverse impact on the volumetric gas flow rates calculated from these molecular weights.

TABLE 8-3. COMPOUNDS PRESENT IN GAS STREAMS FOR WHICH GC CONDITIONS WERE OPTIMIZED

Plant No.	Compounds
C-1	Methylisobutyl ketone (MIBK), toluene, xylenes, ethylbenzene
C-3	C_{12}-C_{18} hydrocarbons
C-4	MIBK, cellosolve, xylenes, ethylbenzenes
C-5	Phenols, cresols, aromatics
C-6	Methyl ethyl ketone (MEK), toluene, xylenes, isopropyl alcohol, n-butyl alcohol, cellosolve acetate

8.2.4 Gas Chromatograph/Mass Spectrometer (GC/MS) Analyses

This section defines the changes and gives the rationale for modifying GC/MS procedures defined in the Quality Assurance Project Plan. Initial rationale of sample acquisition and subsequent GC/MS analyses were based on the assumption that only low molecular weight (highly volatile) organic solvents would be present. No pretest surveys had been conducted at the writing of the original Quality Assurance Project Plan (September 20, 1982). Once the pretest survey data began to be gathered, it was obvious that additional protocols were necessary. Some of these were addressed in the revised Quality Assurance Project Plan (December 7, 1982); however, some additional changes were mandated and are documented here. This section is divided into sample types with acquisition procedures and the GC/MS analytical procedures.

8.2.4.1 Sample Types and Sample Acquisition--

Again, low molecular weight (highly volatile) organics were expected at the initiation of this project. Canister sampling is a well-defined technique to obtain either grab or integrated samples for gas phase organics up to about decane in volatility (also depending, of course, on concentration). At sites C-2 and C-3, heavy hydrocarbons (C_{12}-C_{18}) were expected from the site surveys; therefore, the impinger catches for the EPA Method 4 moisture determinations were chosen as a good source of these heavy compounds for identification. Extractions were performed on the impinger catches and were subjected to GC/MS analysis to confirm the site survey information. Even this procedure was thought not to be adequate for site C-5 where phenolics (substituted phenols) were being used to coat wire. Condensation could have occurred even in the heated sampling lines of the EPA Method 4 procedures; therefore, grab samples of the starting material (liquid) were taken for GC/MS analysis along with an impinger catch.

Table 8-4 contains the actual number and types of samples taken at each site. Note the types of organic species observed and the types of liquid samples taken based on the above rationale.

TABLE 8-4. SAMPLES OBTAINED FOR GC/MS ANALYSIS AT EACH SITE

Site Number	Number of Samples			Species Observed
	Canisters	Impinger Catches	Grab Samples of Liquids	
C-1 (2)	4	-	-	Low molecular weight solvents
C-2*	-	-	-	-
C-3 (2)	4	4	-	C_{12}-C_{18} hydrocarbons (semivolatile)
C-4	2	-	-	Low molecular weight solvents
C-5	-	1	2	Phenolic materials (nonvolatile)
C-6	4	-	-	Low molecular weight solvents

*Incinerator not tested due to catalyst failure indicated by temperature drop across catalyst

8.2.4.2 GC/MS Analytical Procedures--

The three types of samples taken can be injected into the GC/MS by either cryogenic trapping (canister samples) or direct injection of a liquid (impinger extracts and grab samples of liquids). Analysis and quality control for liquid samples were not described in the original Quality Assurance Project Plan, but were noted in the revised edition (12/7/82). Additional steps and changes are documented in this section. These include changing from a Finnigan GC/MS based in Sacramento to a Hewlett-Packard GC/MS (see Table 8-5) based in Austin. At the writing of the Quality Assurance Project Plan, only Radian's Sacramento office had GC/MS instrumentation equipped with cryogenic trapping systems. Before samples were actually taken, the Austin laboratory obtained this capability. Since the field teams were staffed primarily from Austin, samples could more easily be shipped back to Austin for analysis.

With liquids for GC/MS analysis, a second set of conditions were needed to analyze the heavier molecular weight organics. Table 8-5 contains the conditions used for both the cryogenic trapping method and for injection of the liquids. The same multipurpose column was used for both types of analyses, as indicated. An on column injection technique was used for the liquids.

System quality control for the GC/MS was followed as stated in the revised Quality Assurance Project Plan. These quality control steps included (1) calibration by perfluorotributylamine for tuning the MS, and (2) daily calibration with bromofluorobenzene for volatiles and/or decafluorotriphenylphosphine for extractables. In addition to these defined quality control measures, d_8-toluene was spiked as an internal standard into each volatile sample and d_{10}-phentharene was spiked as an internal standard into the extractable or grab samples.

Two exceptions to the quality control procedures were the lack of duplicate canisters taken and the lack of blank canisters analyzed by GC/MS. The changing of product mixtures (coatings) at the plant prevented duplicates

TABLE 8-5. GC/MS CONDITIONS FOR ANALYSIS OF CANISTER SAMPLES

GC/MS Conditions

Instrument	Hewlett-Packard 5985	
Ionization voltage	70 eV	
Scan rate	∿1 scan/sec	
Scan range	50-350 amu	
Column	30 meter DB-5 Fused Silica coated with 95% dimethyl-5%-diphenyl-polysiloxane	
	Cryotrap	Injection
Initial temperature	-50°C	35°C
Initial hold	2 min	2 min
Program rate	8°/min	30°/min→100°C then 8°/min
Final temperature	200°C	300°C
Interface	Open split with fused silica column attached directly to source	

Trap Conditions

Cryogenic trap temperature	-183°C
Desorption temperature	+250°C
Desorption time	10 min

being taken in some instances. Where samples were taken after coating changes, similar components were seen in the GC/MS analyses. As indicated in the Quality Assurance Project Plan, the GC/MS analyses were intended only to provide qualitative data. Samples taken after coating changes represented duplicates in a qualitative sense, as seen by the results. Instrument or "system" blanks were analyzed on the GC/MS and much documentation is available for canister cleanliness from other projects involving ambient air. No canister has been analyzed with blanks greater than 100 ppbv-C which is orders of magnitude lower than the samples obtained on this incinerator project. The final report, "Evaluation of VOC Emission from Wastewater Systems (Secondary Emissions)," EPA Contract No. 68-03-3038 contains a great deal of information pertaining to documentation of canister blanks.

8.2.5 Volumetric Gas Flow Rate

At all six catalytic test sites, measurement of the gas flow rate at both the incinerator inlet and outlet was not possible. Acceptable EPA Method 2 sampling locations did not exist at both places.

In cases where the inlet gas flow rate could not be measured, the inlet flow rate was estimated according to the following equation:

$$Q_{in} = Q_{out} - Q_{CA} - Q_F$$

where,

Q_{in} = inlet gas rate, Nm^3/sec
Q_{out} = outlet gas rate, Nm^3/sec
Q_{CA} = combustion air rate, Nm^3/sec
Q_F = fuel usage rate, Nm^3/sec

Combustion air and fuel usage rates were either measured or estimated. The method used to obtain these rates varied for each plant and is discussed in the site-specific interim test reports. For plants where the outlet gas flow rate could not be measured, the following equation was used:

$$Q_{out} = Q_{in} + C_{CA} + Q_F$$

At one test site, neither the inlet nor outlet gas flow rate could be measured. In this case, the gas flow rates were estimated by performing a mass balance for CO_2 and total gas mass around the inlet blower. Details of the method used to determine the gas flow rates are discussed in the interim test report for Plant C-1.

8.2.6 Additional Process Data

Section 4.6 of the Quality Assurance Project Plan indicated that several additional process parameters would be determined or obtained for each incinerator. These parameters included pressure readings, temperature profiles, auxiliary fuel characteristics (type, flow rate, and heating value), combustion air characteristics (where applicable), and heat recovery characteristics (type, efficiency, and energy contribution). These parameters were characterized, where applicable, although measurement/determination procedures varied from site to site.

A major addition to the testing procedures was made at Plant C-3 and continued on through subsequent plants. On December 13, 1982, an Esterline Angus 24 channel temperature recorder was put into service at Plant C-3 to continuously monitor temperatures in the inlet and outlet SLA streams and the inlet and outlet areas of the catalyst bed. An identical recorder was used for the same purposes at Plants C-4, C-5, and C-6. In all cases, a type K thermocouple probe was installed in the sample point and sufficient thermocouple wire run from the sample probe to the recorder. Both recorders had been calibrated (NBS traceability) by the supplier within 2 days of Radian's placing them in service.

In addition to those parameters specified in the Quality Assurance Project Plan, certain design and operating characteristics of the incinerators were measured or obtained. These included incinerator design specifications, catalyst characteristics, and auxiliary energy consumption (e.g., blower horsepower). Another major addition to the data, although not addressed in the Quality Assurance Project Plan, involved characterization of the coating operation. This characterization allowed major correlations to be developed between incinerator performance and coating conditions. The data on the coating operation varied in type from site to site, but typically included information on the steadiness of the coating operation (off vs. on times), coating rates, solvent types and properties, type of coater, web type, web width, and web speed.

8.3 CALIBRATION PROCEDURES

In addition to the modifications to the sampling/analytical procedures and techniques discussed above, some details of the calibration procedures used during field testing differed somewhat from those originally described in the Quality Assurance Project Plan. This section addresses these modifications.

8.3.1 Temperature Calibration

During testing at Plant C-3, an Esterline Angus 24 channel temperature recorder was obtained and used at each plant thereafter. Various process temperatures were continuously recorded using this instrument and Type K thermocouples installed at each of the sample points. Calibration of the recorder was performed on December 8, 1982 by the vendor (Leasametric, Inc.) in their laboratory in Gaithersburg, Maryland. Details of their calibration procedure are as follows:

- The amplifier zero was set with an appropriate thermocouple (Type K) immersed in an ice bath (32°F);

- The amplifier gain was set by supplying an upscale voltage from a Fluke Model 335D millivolt generator;

- Linearity and accuracy were then checked at several points throughout the span range.

Millivolt signals corresponding to a given temperature were taken from the latest NBS conversion chart. Accuracy of the Fluke 335D is given as ±0.1 millivolts at its full scale value at 10 volts. This unit was calibrated against a Fluke Model 7105 voltage generator which was, in turn, calibrated against a Guildline 9154D standard cell enclosure. The standard cell had been calibrated against a standard by the Research Council of Canada whose standard had been calibrated by the United States National Bureau of Standards. The Leasametrics calibration of the Esterline Angus recorder was guaranteed for 90 days. Independent audits by Research Triangle Institute, North Carolina, of the temperature multipoint recorders indicated errors of 20-29°F.

Data collected by Radian at Plants C-3, C-4, and C-6 indicate that the Esterline-Angus temperature recorders were not in error to the degree suggested by the RTI audits. Limited data are available on the temperature recorder audited at Plant C-3. However, these data, which are shown in Table 8-6, indicate that the multipoint recorder was not in error by 25-35°F as stated by RTI.

Considerably more data are available for the Plant C-4 recorder, which was also used at Plants C-5 and C-6. Data collected at Plants C-4 and C-6 are shown in Tables 8-7 and 8-8. The average temperature difference between the multipoint recorder and a Keithley digital thermometer at Plant C-4 was 6.4°F on the incinerator inlet, 13°F at the catalyst inlet and 14°F at the catalyst outlet. At Plant C-6, the temperature difference between the

TABLE 8-6. TEMPERATURE DATA FOR PLANT C-3

Temperature Location	Type of Readout		
	Plant Console	Keithley[a]	Multipoint[b]
catalyst inlet	664°F	666°F	670°F
catalyst outlet	783°F	786°F	790°F

[a] Handheld digital readout calibrated at Radian

[b] Esterline-Angus recorder audited by RTI

TABLE 8-7. TEMPERATURE DATA FOR PLANT C-4

		Inc. Inlet		Catalyst Inlet		Catalyst Outlet	
Date	Time	Multipoint	Keithley[a]	Multipoint	Keithley[a]	Multipoint	Keithley[a]
2/1	0814	235	233	620	606	720	711
2/1	1627	255	246	585	595	670	681
2/2	0930	340	330	645	633	755	732
2/2	1208	330	323	625	620	750	738
2/2	2101	330	327	630	629	735	735
2/4	2100	330	-	715	734	875	879
2/4	2145	335	326	705	735	860	876
2/4	2324	335	328	735	719	870	823
2/5	0827	316	312	624	635	770	770

---

[a] Two different handheld devices calibrated at Radian

TABLE 8-8. TEMPERATURE DATA FOR PLANT C-6

		Inc. Inlet		Catalyst Inlet		Catalyst Outlet	
Date	Time	Multipoint	Plant[a]	Multipoint	Plant[b]	Multipoint	Plant[c]
2/25	1712	-	-	545	552	740	736
2/28	0733	-	-	545	550	780	780
2/28	1636	-	-	540	550	780	787
2/28	1800	-	-	530	553	785	782
3/1	1756	350	351	545	551	830	817
3/2	0845	355	351	540	553	820	834
3/2	1252	355	355	645	661	855	867
3/2	1158	190	182	490	550	645	672
3/2	1607	285	283	550	565	705	702
3/3	2112	315	315	645	660	830	835
3/4	1738	250	253	530	545	815	782

---

[a] Plant incinerator inlet temperature digital readout

[b] Plant catalyst inlet temperature digital readout

[c] Plant catalyst outlet temperature digital readout

multipoint recorder and the various plant digital readout thermometers was 2.6°F for the incinerator inlet, 17°F for the catalyst inlet and 11°F for the catalyst outlet. Thus, the audit results do not agree well with the data presented in the tables. The NBS-traceable calibration of the multipoint recorder performed just prior to testing also tends to raise questions about the RTI audit results.

8.3.2 Calibration Procedures for Methods 18 and 25A

In general, the calibration procedures specified in the revised Quality Assurance Project Plan were followed. Deviations occurred in two areas.

- Multipoint calibrations were conducted at least as often as specified. At Plants C-3, C-5, and C-6, multipoint propane calibrations were performed each day for each VOC analyzer (i.e., both Methods 18 and 25A).
- Drift checks and RF checks were seldom performed independently of multipoint calibrations.

With the modifications to the sampling system described in Section 8.2.2, each sample manifold was capable of supplying a homogeneous gas sample to all of the analyzers connected to it. Thus, when the daily calibrations of the THC analyzers were being conducted, concurrent calibration of the Method 18 analyzers was possible by simply injecting the gas already flowing through it. Advantage was taken of this situation whenever possible.

The testing schedule deviated considerably from that originally planned. Briefly, instead of discrete 2-hour experimental runs with distinct start and stop times, the THC analyzers were utilized almost continuously. Thus, each common manifold line was filled with SLA sample gas most of the time.

The original Quality Assurance Project Plan called for Methods 25A and 18 drift checks daily at the conclusion of testing and for RF checks for Method 18 daily prior to testing. With the test schedule just described, there was no definitive time that corresponded to "at the conclusion" or "prior to" testing. In general, arbitrary times were picked for complete calibration and the appropriate data evaluated as RF checks or drift checks. In most cases, no more than 24 hours elapsed between full calibrations.

At those plants where a single instrument was used for Method 18 analyses, the calibration and other QC procedures specified for inlet SLA analyzers were used. Whenever possible, conditions corresponding to outlet analyzer calibration were also performed. This was particularly true for blank analyses and control standard analyses.

Further discussion of the detailed calibration and QC check data from each plant is presented in Section 8.5.

8.3.3 Byron CO_2 Analyses

The revised Quality Assurance Project Plan specified daily analysis of a "mixed gas standard" for the Byron 401 analyzer in the full scan mode and for the Byron 301. The fact that this would serve as a single point calibration of CO_2 analyses by the Byron 401 was not mentioned and no other QC requirements were specified.

During testing at each plant, the Byron 401 was periodically put in the Full Scan mode to analyze the outlet SLA stream for THC, NMHC, CO, CH_4, and CO_2. In the case of CO_2 analyses, concentrations were derived using the daily single point RF from the mixed gas calibration. These values served primarily as checks for the CO_2 values from the modified EPA Method 3 analyses, but in some cases were actually used in calculating molecular weight of the sample gas.

8.3.4 Byron Methane Analyses

Methane analysis of the outlet SLA using the Byron 401 was not mentioned in the revised Quality Assurance Project Plan. The calibration and data acquisition sequences described for CO_2 were also used for methane. However, the data thus obtained represent the only methane analyses performed on outlet SLA streams at any plant.

Calibration of the Byron 301 for methane using the mixed gas standard was specified as a daily requirement. At the plants where the Byron 301 was used for inlet SLA analysis, this requirement was met. In the plants where a modified GC/FID instrument was used for inlet SLA analyses, no separate calibration or analysis for methane was performed since the GC/FID instrument did not separate methane from other organics.

8.4 DATA REDUCTION

Data reduction procedures used during this program were essentially consistent with those presented in the Quality Assurance Project Plan. There are, however, two exceptions. First, Equation 7-7 in the Quality Assurance Project Plan indicates that in calculating Method 25A THC concentration, the response factor (RF) derived from the multipoint propane calibration would also be used as the methane RF. In practice, this was not the case. Rather, as discussed above in Section 8.3.4, a methane response factor was derived independently, thus improving the quality of the methane data.

The second exception to the data reduction procedures presented in the Quality Assurance Project Plan is related to Equations 7-8 through 7-10, which deal with applying response correction factors for the various species to the Method 25A data. However, in order to maximize data comparability, and because of the complexity of some of solvent mixtures, this correction for variability in FID response for various species was not performed. Rather, all Method 25A non-methane hydrocarbon data was quantitated relative to propane.

8.5 DATA VALIDATION

One aspect of the data validation effort described in Section 7 of the Quality Assurance Project Plan was evaluation of the QC check and calibration data in light of the acceptance criteria presented in Table 8-1 of the Quality Assurance Project Plan. For the most part, this was an ongoing evaluation/validation effort throughout the course of the project.

Tables 8-9 and 8-10 present a summary of the QC checks and calibration requirements for Methods 25A and 18 respectively, indicating whether or not each of the acceptance criteria were met each day. In instances where an acceptance criterion was not met, the degree of deviation is noted in footnotes to the table.

Data for test periods during which a particular QC check failed to meet the prescribed criteria is not necessarily considered to be invalid data. In other words, these data are useful, although the limitations associated with them may be somewhat different than for the bulk of the data. The purpose of the QC checks, in addition to control function, was to provide this mechanism for assessing and qualifying the measurement data.

TABLE 8-9. METHOD 25A DATA VALIDATION SUMMARY

	Inlet							Outlet						
Date	Calibration Validation	Control Sample		Blank	Multipoint Calibration		Drift Check	Calibration Validation	Control Sample		Blank	Multipoint Calibration		Drift Check
		CV<5%/	Within 10% RM	S=Sampling A=Analytical	CC>.995/	Within 10% RM			CV<5%/	Within 10% RM	S=Sampling A=Analytical	CC>.995/	Within 10% RM	
C-1														
11-11-82	Yes	Yes	NA	Yes-S	Yes	NA	NA	Yes	Yes	NA	Yes-S	Yes	NA	NA
11-13-82	NA	Yes	Yes	Yes-A	Yes	Yes	*	NA	Yes	Yes	Yes-A	Yes	Yes	*
11-15-82	NA	Yes	Yes	Yes-A	Yes	No[a]	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
11-17-82	NA	*	*	Yes-A	Yes	Yes	No[c]	NA	*	*	Yes-A	Yes	No[b]	Yes
11-18-82	NA	Yes	No[d]	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	No[e]	Yes
11-21-82	NA	*	*	Yes-S	Yes	Yes	Yes	NA	*	*	Yes-S	Yes	No[b]	No[f]
11-23-82	NA	Yes	Yes	Yes-A	Yes	Yes	No[c]	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
C-3														
1-19-83	*	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
1-20-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
1-22-83	NA	*	*	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
1-23-83	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	Yes	Yes	Yes	Yes-A	Yes	Yes	Yes
1-24-83	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
1-26-83	NA	*	*	Yes-A	Yes	Yes	No[g]	Yes	*	*	Yes-A	Yes	Yes	Yes
1-27-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
1-28-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
C-4														
1-31-83	Yes	Yes	Yes	Yes-S	Yes	Yes[b]	*	No[h]	Yes	Yes	Yes-S	Yes	No[h]	*
2-1-83	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
2-2-83	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
2-3-83	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
2-4-83	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
2-5-83	NA	NA	NA	*	Yes	No[j]	Yes	NA	NA	NA	Yes-S	Yes	Yes	Yes
C-5 - Byron 301 not used at this plant. GC was used instead														
2-14-83	*	*	*	Yes-A	Yes	Yes	*	*	*	*	Yes-A	Yes	Yes	*
2-15-83	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
2-16-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	NA	Yes	Yes	Yes-S	Yes	Yes	No[f]
2-17-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	NA	Yes	Yes	Yes-S	Yes	Yes	Yes
2-19-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	NA	Yes	Yes	Yes-S	Yes	No[i]	Yes
C-6														
2-24-83	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	No[k]	Yes
2-28-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	NA	Yes	Yes	Yes-S	Yes	Yes	Yes
3-1-83	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
3-2-83	NA	Yes	Yes	Yes-A	Yes	Yes	*	NA	Yes	Yes	Yes-A	Yes	Yes	*
3-3-83	NA	*	*	Yes-A	Yes	Yes	Yes	NA	*	*	Yes-A	Yes	Yes	Yes
3-4-83	NA	Yes	Yes	Yes-S	Yes	Yes	Yes	NA	Yes	Yes	Yes-S	Yes	Yes	Yes

*Not Analyzed

NA = Not Applicable

[a] Criteria not met for Byron 301. Average RF within 15% of running mean

[b] Criteria not met for Byron 401. Average RF within 11% of running mean

[c] Criteria not met for Byron 301. Calibration drifted 1.1%

[d] Byron 301 criteria not met. Mean value = 110.55% of running mean

[e] Criteria not met for Byron 401. Average RF within 12% of running mean

[f] Criteria not met for Byron 401. Calibration drifted 1.1%

[g] Instrument drifted 1.2%

[h] Criteria not met for Byron 401. % difference = 10.8

[i] Criteria not met for Byron 301. Average RF within 14% of running mean

[j] Criteria not met for Byron 401. Average RF within 13% of running mean

[k] Criteria not met for Byron 401. Average RF within 20% of running mean

TABLE 8-10. METHOD 18 DATA VALIDATION SUMMARY

Date	Inlet							Outlet						
	Calibration Validation	Control Sample CV<5%/	Control Sample Within 10% RM	Blanks Sampling/Analytical	Single Point Ref.	Drift Check	Linearity Check	Calibration Validation	Control Sample CV<5%/	Control Sample Within 10% RM	Blanks Sampling/Analytical	Single Point Ref.	Drift Check	Linearity Check
C-1														
11-10-82	Yes	Yes	NA	Yes-A	Yes	NA	Yes	Yes	Yes	NA	Yes-A	Yes	NA	Yes
11-11-82	NA	Yes	Yes	Yes-S	Yes	Yes	NA	NA	Yes	Yes	Yes-S	Yes	Yes	NA
11-15-82	Yes	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
11-16-82	NA	*		Yes-A	Yes	Yes	NA	NA	*		Yes-A	Yes	Yes	NA
11-17-82	NA	*		Yes-A	Yes	Yes	NA	NA	*		Yes-A	Yes	Yes	NA
11-18-82	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
11-19-82	NA	Yes	Yes	*	Yes	Yes	NA	NA	*	*	*	Yes	Yes	NA
11-20-82	NA	Yes	Yes	Yes-S	Yes	Yes	NA	NA	a	a	a	a	a	NA
11-22-82	NA	Yes	Yes	Yes-A	Yes	Yes	Yes	NA	Yes	Yes	Yes-A	Yes	Yes	Yes
11-23-82	NA	Yes	Yes	Yes-A	Yes	No[b]	NA	NA	Yes	Yes	Yes-A	Yes	No[c]	NA
C-3 - One instrument used for both inlet and outlet														
1-20-83	Yes	Yes	Yes	Yes-S	(Multi-	NA	Yes	No[e]	Yes	Yes	Yes-S	(Multi-	NA	Yes
1-22-83	NA	Yes	Yes	Yes-S	point[d]	No[f]	Yes	NA	Yes	Yes	Yes-S	point[d]	No[g]	Yes
1-23-83	NA	Yes	Yes	Yes-S	cali-	No[h]	Yes	NA	Yes	Yes	Yes-S	cali-	No[i]	Yes
1-24-83	Yes	Yes	Yes	Yes-A	bration	Yes	Yes	Yes	Yes	Yes	Yes-A	bration	Yes	Yes
1-26-83	NA	*	*	*	done	No[j]	Yes	NA	*	*	*	done	No[k]	Yes
1-27-83	NA	Yes	Yes	Yes-A	each	No[l]	Yes	NA	Yes	Yes	*	each	Yes	Yes
1-28-83	NA	Yes	Yes	Yes-S	day)	Yes	Yes	NA	Yes	Yes	*	day)	Yes	Yes
C-4														
1-31-83	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
2-1-83	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
2-2-83	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
2-3-83	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
2-4-83	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	No[m]	NA
2-5-83	NA	NA	NA	*	Yes	NA	Yes	NA	NA	NA	*	Yes	NA	Yes
C-5														
2-16-83	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes	Yes	Yes	Yes	Yes-S	Yes	Yes	Yes
2-17-83	NA	Yes	Yes	Yes-S	Yes	Yes	NA	NA	Yes	Yes	Yes-S	Yes	Yes	NA
2-19-83	NA	Yes	Yes	Yes-S	Yes	NA	Yes	NA	Yes	Yes	Yes-S	Yes	NA	Yes
C-6														
2-24-83	Yes	Yes	Yes	Yes-S	Yes	n	Yes	Yes	Yes	Yes	Yes-S	Yes	n	Yes
2-28-83	NA	Yes	Yes	Yes-S	Yes	Yes	NA	NA	Yes	Yes	Yes-S	Yes	Yes	NA
3-1-83	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
3-2-83	NA	Yes	Yes	Yes-A	Yes	Yes	NA	NA	Yes	Yes	Yes-A	Yes	Yes	NA
3-3-83	NA	Yes	Yes	a	Yes	Yes	NA	NA	Yes	Yes	*	Yes	Yes	NA
3-4-83	NA	Yes	Yes	Yes-S	Yes	NA	Yes	NA	Yes	Yes	Yes-S	Yes	NA	Yes

*Not Analyzed

NA = Not Applicable

[a] GC down for repairs

[b] Power to the instrument was off overnight - Instrument drift was 11%

[c] Power to the instrument was off overnight - Instrument drift was 12%

[d] All mean RF values fall within 20% of the running mean except for 1-22-83 which was 53% higher

[e] 18.7% difference

[f] Instrument drifted 32%

[g] Instrument drifted 50%

[h] Instrument drifted 33%

[i] Instrument drifted 54%

[j] Instrument drifted 28%

[k] Instrument drifted 12%

[l] Instrument drifted 25%

[m] Instrument drifted 13%

[n] No drift check - only 2 samples analyzed

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APPENDIX A

PERFORMANCE AUDIT DATA SHEETS

ANALYZER ACCURACY

Date 1/24/83

Site C-3

Engineer

Calibrator

Serial No.

Instrument Model

Instrument S/N ANTEK (INLET)

Instrument Range

Source Gas Cyl. No.

Cylinder Concentration

Parameter Audited SPECIATED HC's (METHOD 18)

USING C_3H_8 IN AIR

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
			0	0	—
E4			303	136	-55.1
43-1			2159	1319	-38.9
43-3			1379	805	-41.6
43-4			712	361	-49.3
				Average Δ%	-46.2

Slope 0.620

Intercept -40.3

Correlation 0.998

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ANALYZER ACCURACY

Date 1/24/83

Site C-3

Engineer

Calibrator

Serial No.

Instrument Model TRACOR (OUTLET)

Instrument S/N

Instrument Range

Source Gas Cyl. No.

Cylinder Concentration

Parameter Audited THC

USING PROPANE IN AIR

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
43-4			712	585	-17.8
E-4			303	295	-2.6
43-5			48	60.5	26.0
43-6			234	234	0.0
43-7			712	609	-14.4
			0	~~AVERAGE Δ%~~ 2.4	—

AVERAGE Δ% = -1.8

Slope 0.81

Intercept 24.9

Correlation 0.997

ANALYZER ACCURACY

Date 1/24/83

Site C-3

Engineer

Calibrator

Serial No.

Instrument Model TRACOR (INLET)

Instrument S/N

Instrument Range

Source Gas Cyl. No.

Cylinder Concentration

Parameter Audited THC METHOD 25A

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
77-1			1189	997	-16.1
E4			303	286	-5.6
43-1			2159	1872	-13.2
43-3			1379	1247	-9.6
43-4			712	591	-16.9
			0	~~Average Δ%~~ 2.4	—

Ave Δ% = -12.3

Slope 0.867

Intercept 1.94

Correlation 0.999

ANALYZER ACCURACY

Date 1/24/83

Site C-3

Engineer

Calibrator

Serial No.

Instrument Model BYRON 401

Instrument S/N (OUTLET)

Instrument Range

Source Gas Cyl. No.

Cylinder Concentration

Parameter Audited THC

METHOD 25A

USING PROPANE IN AIR

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
43-7			712	614	-13.7
43-4			712	585	-17.8
43-6			234	226	- 3.4
43-5			48.4	39	-19.4
E-4			303	285	- 5.9
			0	~~Average Δ%~~ 1.15	—

AVG Δ% - 12.0

Slope 0.834

Intercept 12.3

Correlation 0.998

ANALYZER ACCURACY

Date 1/24/83

Site C-3

Engineer

Calibrator

Serial No.

Instrument Model BYRON 401

Instrument S/N [illegible]

Instrument Range

Source Gas Cyl. No.

Cylinder Concentration

Parameter Audited CO

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
37-1			1010	1269	25.6
27-3			248	299	20.6
E3			44	50.0	13.6
			0	2.5	—
				Average Δ%	19.9

Slope 1.26

Intercept -4.66

Correlation 0.999 +

ANALYZER ACCURACY

Date 1/24/83

Site C-3

Calibrator

Engineer

Serial No.

Instrument Model Fisher

Source Gas Cyl. No.

Instrument S/N

Cylinder Concentration

Instrument Range

Parameter Audited O2

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
			0	0.05	—
36-1			21.2	20.3	-4.2
36-2			11.5	11.2	-2.6
36-3			1.28	1.32	3.1
E-2			8.04	8.19	1.9
				Average Δ%	-0.46

Slope 0.955

Intercept 0.184

Correlation 0.999 +

ANALYZER ACCURACY

Date 1/24/83

Site C-3

Engineer

Calibrator

Serial No.

Instrument Model FISHER

Instrument S/N

Instrument Range

Source Gas Cyl. No.

Cylinder Concentration

Parameter Audited CO2

	Source Flow SCCM	Dilution Flow SCCM	Input Concentration (ppm), A	Analyzer Response (ppm), B	Percent Difference $\frac{B-A}{A} \times 100 = \%$
			0	0	—
36-1			15.9	14.2	-10.7
36-2			8.65	8.16	-5.7
36-3			0.96	0.91	-5.2
E1			3.77	3.47	-8.0
				Average Δ%	-7.4

Slope 0.897

Intercept 0.093

Correlation 0.999 +

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Site T-3

Auditor DLLewis

Instrument Model BYRON 301 (INLET)

Instrument S/N

Parameter Audited NMHC / METH 25A

Audit Standard PROPANE IN AIR (BY DILUTION OF CYL # AAL7065) AND PROPANE IN N_2 (SAMP # E-4, EPA CYL # LL12015)

Sample No.	Location	Actual Conc. (PPMV-C)	Measured Conc. (PPMV-C)	Error (PPMV-C)	Relative Error (%)
43-4	INLET	853	755	-98	-11.4
43-5	INLET	1743	1711	-32	-1.8
43-6	INLET	2631	2564	-67	-2.5
E-4	INLET	303	299	-4	-1.3
			AVERAGE	-50	-4.2

Comments: STANDARD DEVIATION OF RELATIVE ERROR = 4.8

Regression Parameters:

Slope 0.988

Intercept -33.0

Correlation 0.9992

PERFORMANCE AUDIT RESULTS

Date 4/6/83
Instrument Model BYRON 401 (OUTLET)
Site T-3
Instrument S/N
Auditor DL LEWIS

Parameter Audited THC / METH 25A

Audit Standard PROPANE IN AIR (BY DILUTION OF CYL # AAL 7065) AND PROPANE IN N_2 (SAMP # E-4, EPA CYL # LL12015)

Sample No.	Location	Actual Conc.	Measured Conc.	Error	Relative Error
43-2		78.4	70.2	- 8.2	-10.4
43-3		243	212	-31	-12.8
E-4		303	275	-28	-9.2
Z-1		0	0.6	0.6	—
			AVERAGE	-17	-10.8

Comments: STANDARD DEVIATION OF RELATIVE ERROR = 1.8

Regression Parameters:

Slope 0.895
Intercept -0.22
Correlation 0.9995

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model TRACOR 560

Site T-3

Instrument S/N

Auditor DLLEWIS

Parameter Audited NMHC/METH. 18

Audit Standard PROPANE IN AIR (BY DILUTION OF CYL # AAL 7065) AND PROPANE IN N_2 (SAMP # E-4, CYL # LL12015)

Sample No.	Location	Actual Conc. (PPMV-C)	Measured Conc. (PPMV-C)	Error (PPMV-C)	Relative Error (%)
43-2	OUTLET	78.4	70.2	-8.2	-10.4
43-3	OUTLET	243	237	-6	-2.5
43-4	INLET	853	755	-98	-11.4
43-5	INLET	1743	1745	2	0.1
43-6	INLET	2631	2568	-63	-2.4
Z-1	OUTLET	0	0	0	—
E-4	OUTLET	303	306	3	1.0
E-4	INLET	303	306	3	1.0
			AVERAGE	-24*	-4.2*

Comments: STANDARD DEVIATION OF THE RELATIVE ERROR = 5.3

Regression Parameters: *(SAMP E-4 RESULTS ENTERED AS ONE POINT)

Slope 0.982

Intercept -9.60

Correlation 0.9993

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model Byron 301 (INLET)

Site T-3

Instrument S/N

Auditor DL Lewis

Parameter Audited THC / METH 25A

Audit Standard MEK IN AIR (BY DILUTION OF CYL #AAL9626)

Sample No.	Location	Actual Conc. (PPMV-C)	Measured Conc. (PPMV-C)	Error (PPMV-C)	Relative Error (%)
88-1	INLET	49.8	36.2	-13.6	-27.3
88-2	INLET	341	294	-47	-13.7
88-3	INLET	820	745	-75	-9.1
				-45	-16.7

Comments: STANDARD DEVIATION OF RELATIVE ERROR = 9.5

Regression Parameters:

Slope 0.922

Intercept -13.9

Correlation 0.9999

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model BYRON 401 (OUTLET)

Site T-3

Instrument S/N

Auditor DL LEWIS

Parameter Audited THC/METH 25A

Audit Standard MEK IN AIR (BY DILUTION OF CYL # AAL 9626)

Sample No.	Location	Actual Conc. (PPMV-C)	Measured Conc. (PPMV-C)	Error (PPMV-C)	Relative Error (%)
88-1	OUTLET	49.8	38.3	11.5	-23.1

Comments:

Regression Parameters:

Slope

Intercept

Correlation

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model BYRON 301

Site T-3

Instrument S/N

Auditor DLLEWIS

Parameter Audited NMHC/METH 25A/INLET

Audit Standard C_2-C_{10} HYDROCARBON MIX (CYL# AAL 8823)

Sample No.	Location	Actual Conc. (PPMV-C)	Measured Conc. (PPMV-C)	Error (PPMV-C)	Relative Error (%)
77-1	INLET	1189	1423	234	19.7

Comments:

Regression Parameters:

Slope

Intercept

Correlation

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model BYRON 401

Site T-3

Instrument S/N

Auditor DLLEWIS

Parameter Audited THC/METH 25A/OUTLET

Audit Standard C_2-C_{10} HYDROCARBON MIX (CYL # AAL 8823)

Sample No.	Location	Actual Conc. (PPMV-C)	Measured Conc. (PPMV-C)	Error (PPMV-C)	Relative Error (%)
77-1	OUTLET	1189	945	-244	-20.5

Comments:

Regression Parameters:

Slope

Intercept

Correlation

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model TRACER 560

Site T-3

Instrument S/N

Auditor DLLEWIS

Parameter Audited NMHC / METH 18

Audit Standard MEK IN AIR (BY DILUTION OF CYL # AAL 9626)

Sample No.	Location	Actual Conc.	Measured Conc.	Error	Relative Error
88-1	INLET	49.8	0 (0)	-49.8 (-49.8)	-100 (-100)
88-2	INLET	341	294 (203)	-47 (-138)	-13.8 (-40.4)
88-3	INLET	820	714 (494)	-106 (-326)	-12.9 (-39.8)
			AVERAGE	-68 (-171)	-42.2 (-60.1)

Comments: MEASUREMENTS MADE USING RF FOR MEK. PARENTHETICAL VALUES REPRESENT RESULTS CALCULATED USING PROPANE RF. STANDARD DEVIATION OF RELATIVE ERROR = 50.0, BASED ON RF FOR MEK, AND 34.6 BASED ON PROPANE RF

Regression Parameters:

Slope 0.922 (0.638)
Intercept -36.1 (-25.2)
Correlation 0.9993 (0.9993)

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model Byron 401

Site T-3

Instrument S/N

Auditor D Lewis

Parameter Audited CO

Audit Standard Scott cyl # AAL 2544 (samp 37-2)
EPA cyl # JJ1621 (samp E-3)

Sample No.	Location	Actual Conc. (ppmv)	Measured Conc. (ppmv)	Error (ppmv)	Relative Error (%)
E-3	Outlet	43.9	43.6	-0.3	-0.6
37.2	Outlet	1010	1034	24	2.4
			Average	11.8	0.9

Comments: Regression parameters calculated using a third point of (0,0)

Regression Parameters:

Slope 1.024
Intercept -0.67
Correlation > 0.9999

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Site T-3

Auditor D L LEWIS

Instrument Model FYRITE O_2

Instrument S/N

Parameter Audited O_2

Audit Standard O_2 IN N_2 CYL # FF5749 (EPA) AND AMBIENT AIR

Sample No.	Location	Actual Conc.	Measured Conc.	Error	Relative Error
E-2	—	8.0	6.6	-1.4	-17.5
A-1	—	20.8	21.0	0.2	1.0
			AVERAGE	-0.6	-8.2

Comments: STANDARD DEVIATION OF RELATIVE ERROR = 13.1

Regression Parameters:

Slope

Intercept

Correlation

PERFORMANCE AUDIT RESULTS

Date 4/6/83

Instrument Model FYRITE CO_2

Site T-3

Instrument S/N

Auditor DLLEWIS

Parameter Audited CO_2

Audit Standard CO_2 IN N_2

Sample No.	Location	Actual Conc.	Measured Conc.	Error	Relative Error
E-1	—	3.8	1.9	1.9	-50

Comments:

Regression Parameters:

Slope

Intercept

Correlation

APPENDIX B

SYSTEMS AUDIT CHECKLISTS

VOLATILE ORGANIC SPECIES

SYSTEMS AUDIT FORM

Contract: CATALYTIC INCINERATION
Date: 1/22/83
Site: C-3
Auditor: DL LEWIS
METHOD 25A

Yes	No	Comments	Operation
			PRESAMPLING PREPARATIONS
✓		BLACKSMITH, RANDALL CHAPMAN, THEILEN	1. Qualified personnel?
✓			2. Spare parts and support equipment available?
✓			3. Instrumentation and apparatus maintained in good condition?
✓		ALL CALIBRATION DATA IN LOGBOOK, ON HARDCOPY (STRIPCHART), AND ON FLOPPY DISKS	4. Instrument certification and/or calibration documentation available?
✓			5. Adequate facilities?
✓			6. Sample line(s) properly located to obtain representative sample?
✓		APPLE II PLUS WITH CUSTOM SOFTWARE	7. Data recording device appropriate for application?
✓			8. Adequate supply of calibration gases and auxiliary gases?
		PROPANE IN N_2	9. Calibration gas mixture appropriate for atmosphere being sampled?
✓		PROPANE IN N_2	10. Separate control standard gas mixture available?
			SAMPLING
✓		TEST "DAYS" NOT NECESSARILY EVEN 24 HR. INTERVALS	11. Instrument response to calibration gas checked and recorded on a daily basis?
✓		SAME AS 11, ABOVE	12. Control standard analyzed on a daily basis?

(Continued)

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VOLATILE ORGANIC SPECIES

SYSTEMS AUDIT FORM (Continued)

METHOD 25A (CONT)

Yes	No	Comments	Operation
✓			13. Appropriate instrument mode used in sampling?
✓			14. Instrument range (scale) used appropriate for measured concentrations?
			POSTSAMPLING
✓		SEE 4 ABOVE	15. Appropriate record keeping procedure for documentation of daily calibrations?
✓		ALL QC DATA, INCL. DRIFT CHECKS, REPLICABILITY & REPEATABILITY FOR CNTRL SAMP INCLUDED IN SOFTWARE PKG. AND STORED ON DISK.	16. Control charts and/or data summary for control sample analyses?
✓		APPLE II PLUS COMPUTER WITH CUSTOM SOFTWARE	17. Adequate system of monitoring data storage?
✓			18. System logbook maintained for records of calibrations, maintenance, malfunctions, etc.?
✓			19. If microprocessor data acquisition and storage system is used, is hardcopy backup available?
✓		ACCEPTANCE CRITERIA INCLUDED IN SOFTWARE — ~~[illegible]~~ AUTOMATIC CHECK FOR ACCEPTABILITY	20. Calibration criteria and control sample criteria used in data validation?

Comments:

VOLATILE ORGANIC SPECIES

SYSTEMS AUDIT FORM

Contract: CATALYTIC INCINERATION

Date: 1/22/83

Site: C-3

Auditor: DL LEWIS

METHOD 18 ANALYSES

Yes	No	Comments	Operation
			PRESAMPLING PREPARATIONS
✓		J.R. BLACKSMITH, J.L RANDALL B. CHAPMAN, C. THEILEN	1. Qualified personnel?
✓			2. Spare parts and support equipment available?
✓			3. Instrumentation and apparatus maintained in good condition?
✓		CALIBRATION LOGBOOK COMPLETE; HARDCOPY FILED IN NOTEBOOK BINDERS (INTEGRATOR OUTPUT)	4. Instrument certification and/or calibration documentation available?
✓			5. Adequate facilities?
✓			6. Sample line(s) properly located to obtain representative sample?
✓		HP INTEGRATOR; DATA SUMMARY SHEETS	7. Data recording device appropriate for application?
✓			8. Adequate supply of calibration gases and auxiliary gases?
		NOT FOR ABSOLUTE ACCURACY, BUT THIS IS NOT REQUIRED; PROPANE, AS SPECIFIED	9. Calibration gas mixture appropriate for atmosphere being sampled?
✓		PROPANE IN N_2	10. Separate control standard gas mixture available?
			SAMPLING
✓		TEST "DAYS" NOT NECESSARILY EVEN 24 HR INTERVALS	11. Instrument response to calibration gas checked and recorded on a daily basis?
✓		SAME AS 11 ABOVE	12. Control standard analyzed on a daily basis?

(Continued)

METHOD 18
(CONT)

VOLATILE ORGANIC SPECIES

SYSTEMS AUDIT FORM (Continued)

Yes	No	Comments	Operation
✓			13. Appropriate instrument mode used in sampling?
✓			14. Instrument range (scale) used appropriate for measured concentrations?
			POSTSAMPLING
✓		HARDCOPY OUTPUT & DEDICATED LOGBOOK	15. Appropriate record keeping procedure for documentation of daily calibrations?
✓		CONTROL CHARTS NOT UP TO DATE; SUMMARY OK	16. Control charts and/or data summary for control sample analyses?
✓		HARDCOPY & DATA SUMMARY SHEETS	17. Adequate system of monitoring data storage?
✓			18. System logbook maintained for records of calibrations, maintenance, malfunctions, etc.?
		N/A	19. If microprocessor data acquisition and storage system is used, is hardcopy backup available?
✓		AS PER QAPP	20. Calibration criteria and control sample criteria used in data validation?

Comments: GAS STREAM PRIMARILY C_{12} TO C_{18} SPECIES; CONDITIONS (CHROMATOGRAPHIC) OPTIMIZED FOR C_{12} TO C_{18} RESULTS IN POOR RESOLUTION OF LIGHTER SPECIES. NOT A PROBLEM.

Catalytic Incineration
Site C-3

1/22/83
DL Lewis

STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE DETERMINATION CHECKLIST TO BE USED BY AUDITOR

Yes	No	Comment	
			Presampling Preparation
✓			1. Knowledge of process conditions.
✓			2. Calibration of pertinent equipment prior to each field test.
			On-Site Measurements
✓			3. Pitot tube meets geometry requirements.
✓			4. Manometer should be carefully leveled and the liquid column set exactly on zero.
			5. Check for cyclonic flow.
✓			6. Leak check after sample run.
✓			7. Sampling port adequately plugged.
✓			8. Process at correct operating level.
✓			9. Pitot tube properly aligned along its roll and pitch axes throughout the traverse.
		N/A	10. Pitot tube frequently cleared when measuring in a dust-laden gas.
✓			11. Manometer has the correct sensitivity.
✓			12. Staying at each traverse point long enough for the system to stabilize.
✓			13. Measuring the stack gas static pressure and temperature.
			Postsampling
✓			14. All information recorded on data form as obtained.
✓			15. Any unusual conditions recorded.
✓			16. Independent check of calculations.
✓			17. Temperature sensor calibrated.

General Comments

CATALYTIC INCINERATION
SITE C-3

1/22/83
DL LEWIS

METHOD 4 CHECKLIST TO BE USED BY AUDITORS

Yes	No	Comment		
				Presampling Preparation
✓			1.	Knowledge of process conditions.
✓			2.	Calibration of pertinent equipment prior to each field test; in particular, the dry gas meter should be checked before each test.
				On-Site Measurements
✓			3.	Leak testing of sample train after sample run.
✓			4.	Addition of water and silica gel to impingers, and correct location of impingers.
✓			5.	Constant sampling rate and not exceeding specified rate.
✓			6.	Measurement of condensed water to within specified limits.
✓			7.	Record of pertinent process condition during sample collection.
✓			8.	Probe maintained at given temperature.
				Postsampling
✓			9.	Calculation procedure/check.
			10.	Calibration checks.

General Comments

APPENDIX C

SAMPLING EQUIPMENT CALIBRATION DATA FORMS

DRY GAS METER CALIBRATION DATA

Date 11/8/82 Calibrated by C.B.C. Meter or Console No. E-342

Barometric pressure, P_b = 29.48 in. Hg Wet Test Meter No. 8494 RAD 5997

Test DGM Flow Rate (ACFM)	Orifice Setting (ΔH) (in. H_2O)	Gas Volumes (ft³) Wet Test Meter Initial	Final	Delta (V_{std})	Dry Gas Meter Initial	Final	Delta (V_{test})	Temperature °F Wet Test Meter Initial	Final	Ave (T_{std})	Dry Gas Meter Inlet Initial	Inlet Final	Outlet Initial	Outlet Final	Ave (T_{test})	Elapsed Time (min) (θ)	Vacuum (2-4 in. Hg)	
.2	.12	122.378	130.258	7.880	115.886	124.146	8.260	70.5	71.0	71	89	93	87	89	90	40.0	3.0	2017 2057
.4	.49	062.135	069.190	7.055	067.312	074.552	7.240	68.5	68.5	68	84	92	80	82	84	20.0	4.0	1358 1418
.6	1.24	042.255	053.809	11.554	046.981	058.993	12.007	67.5	67.85	68	95	101	84	91	93	20.0	2.0	1124 1144
.8	2.253	183.432	195.8	12.253	127.524	139.664	12.137	~~102~~ 75.0	75.0	75.0	102	103	92	93	98.0	15.0	2.9	2115 2155
.8	2.25	185.392	216.204	20.514	139.664	159.850	20.189	75.0	75.0	75.0	93.0	102	92.0	91	95	25.0	2.8	22:20

(.4 & .6 were calibrated on 11/5/82 and the B.P. = 29.72)(.2 & .8 were calibrated on 11/8/82 and the B.P. = 29.48)

Test DGM Flow Rate (ACFM)	Orifice Setting (ΔH)	$Y_1 = \frac{V_{std} P_b (T_{test} + 460)}{V_{test} \left(P_b + \frac{\Delta H}{13.6}\right)(T_{std} + 460)}$	$\Delta H@_1 = \frac{.0317\ \Delta H}{P_b (T_{test} + 460)}$ $\left[\frac{(T_{std} + 460)\theta}{V_{std}}\right]^2$
		~~7.880 29.48 550~~ 8.260 29.48 531 =.98813 7.055 29.72 544 7.240 29.76 528 =1.0026 11.554 29.72 551 =1.0010 12.007 29.81 528 12.253 29.48 535 =.96311 12.137 29.64 555 20.314 29.48 535 20.189 29.65 555 =.96437	
Average		Y =	ΔH@ =

Method 5 Acceptance Criteria

1) $Y_1 = Y \pm 0.02Y$
2) $\Delta H@_1 = \Delta H@ \pm 0.15\ \Delta H@$ (recommended)
3) $\Delta H@ = 1.84 \pm 0.25$ (recommended)
4) Calibration vacuum maintained at 2-4 in. Hg

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PITOT TUBE INSPECTION FORM

Date: 11/8/82 Operator Initials: CRC

Pitot Tube I.D. No.: ____ Length: 4 ft

Pitot tube assembly level? [✓ yes] ____ no

Pitot tube openings damaged? ____ yes (explain below) [✓ no]

Quick connects attached, leak free? ____ yes ____ no

$\alpha_1 = 0°$ $\alpha_2 = 5°$

$\beta_1 = 3°$ $\beta_2 = 1°$

$\gamma = 0°$, $\theta = 1°$, A = (7/8 in) cm (in.)

$z = A \sin \gamma =$ 0 ~~cm~~ (in.);

$w = A \sin \theta =$ 0.015 cm (in.);

$P_A =$ 7/16 ~~cm~~ (in.);

$P_b =$ 7/16 ~~cm~~ (in.);

$D_t =$ 3/8 ~~cm~~ (in.)

Acceptance Criteria:

α_1 and $\alpha_2 < 10°$ [✓ yes] ____ no

β_1 and $\beta_2 < 5°$ [✓ yes] ____ no

$z < 0.32$ cm (1/8 in.) [✓ yes] ____ no

$w < 0.08$ cm (1/32 in.) [✓ yes] ____ no

P_A and P_b, $1.05\ D_t < P < 1.50\ D_t$ ____ yes ____ no

D_t, 0.48 cm (3/16 in) $\leq D_t \leq$ 0.95 cm (3/8 in) ____ yes ____ no

Pitot Tube Acceptable? [✓ yes] ____ no

Comments: ____

PITOT TUBE INSPECTION FORM

Date: 11/8/82 Operator Initials: RFE

Pitot Tube I.D. No.: ______ Length: 6ft.

Pitot tube assembly level? [✓ yes] no

Pitot tube openings damaged? yes (explain below) [✓ no]

~~Quick connects~~ attached, leak free? [✓ yes] no

α_1 = 2 ° α_2 = 2 °

β_1 = 3.0 ° β_2 = 0 °

γ = 2 °, θ = 1 °, A = ~~1.25~~ 15/16 (0.97) ~~cm~~ (in.)

z = A sin γ = ~~0.044~~ 0.033 ~~cm~~ (in.);

w = A sin θ = ~~0.022~~ 0.16 ~~cm~~ (in.);

P_A = ~~9/16~~ 0.47 ~~cm~~ (in.);

P_b = ~~9/16~~ 0.50 ~~cm~~ (in.);

D_t = 3/8 (0.375) ~~cm~~ (in.)

Acceptance Criteria:

α_1 and α_2 < 10° [✓ yes] no

β_1 and β_2 < 5° [✓ yes] no

z < 0.32 cm (1/8 in.) [✓ yes] no

w < 0.08 cm (1/32 in.) [✓ yes] no

P_A and P_b, $1.05\ D_t < P < 1.50\ D_t$ [✓ yes] no

D_t, 0.48 cm (3/16 in) $\leq D_t \leq$ 0.95 cm (3/8 in) [✓ yes] no

Pitot Tube Acceptable? [✓ yes] no

Comments: ______

TEMPERATURE INDICATOR IDENTIFICATION NO. (T_{Test})	NBS THERMOMETER SERIAL NO. (T_{STD})	DATE (MMDDYY)	INITIALS OF CALIBRATOR	CALIBRATION DATA	
				MEASURED °F T_{Test}	MEASURED °F T_{STD}
59678	579609	102982	Cjt	34.0°F	33.2°F
	565139			199.8	197.6
79254	579609			32.8	33.1
	565139			198.0	197.8
K116	579609			33.7	33.7
	565139			202	199.0
	A03864			365	355
T-2	579609			32.3	32.9
	565139	↓	↓	201	197.4
	A03864			336	326

Temperature Calibration Data Sheet Form I

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<table>
<tr><th rowspan="2">TEMPERATURE INDICATOR IDENTIFICATION NO. (T_{Test})</th><th rowspan="2">NBS THERMOMETER SERIAL NO. (T_{STD})</th><th rowspan="2">DATE (MMDDYY)</th><th rowspan="2">INITIALS OF CALIBRATOR</th><th colspan="2">CALIBRATION DATA</th></tr>
<tr><th>MEASURED °F T_{Test}</th><th>MEASURED °F T_{STD}</th></tr>
<tr><td>K111</td><td>579609</td><td>10/29/82</td><td>gt</td><td>33.6</td><td>33.5</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>202</td><td>198.6</td></tr>
<tr><td></td><td>A03864</td><td></td><td></td><td>366</td><td>356</td></tr>
<tr><td>DGM 1</td><td>579609</td><td></td><td></td><td>41</td><td>34.6</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>208</td><td>203.8</td></tr>
<tr><td>DGM 2</td><td>565139</td><td></td><td></td><td>202</td><td>205</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>DGM 3</td><td>579609</td><td></td><td></td><td>30.0</td><td>34.6</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>190</td><td>204.6</td></tr>
<tr><td>DGM 4</td><td>579609</td><td></td><td></td><td>36.0</td><td>34.4</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>204</td><td>206.4</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

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Temperature Calibration Data Sheet Form I

TEMPERATURE INDICATOR IDENTIFICATION NO. (T_{Test})	NBS THERMOMETER SERIAL NO. (T_{STD})	DATE (MMDDYY)	INITIALS OF CALIBRATOR	CALIBRATION DATA	
				MEASURED °F T_{Test}	MEASURED °F T_{STD}
200	579609	102982	CJT	33.2	33.0
	565139			201	198.0
	A03864			353	344
201	579609			32.9	33.0
	565139			202	199.5
	A03864			360	351
202	579609			33.0	33.0
	565139			203	199.7
	A03864			359	350
203	579609			33.1	33.2
	565139			202	198.0°
	A03864			351	342

Temperature Calibration Data Sheet Form I

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TEMPERATURE INDICATOR IDENTIFICATION NO. (T_{Test})	NBS THERMOMETER SERIAL NO. (T_{STD})	DATE (MMDDYY)	INITIALS OF CALIBRATOR	CALIBRATION DATA	
				MEASURED °F T_{Test}	MEASURED °F T_{STD}
5990	579609	102982	CJT	33.2	32.8
	565139			198.0	197.7
9640	579609			32.0°F	32.7
	565139			197.6	197.7
5953	579609			33.2	33.2
	565139			197.8°	198.0°
79241	579609			32.2°F	32.7°
	565139			198°.0	198.0

Temperature Calibration Data Sheet Form I

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<table>
<tr><th rowspan="2">TEMPERATURE INDICATOR IDENTIFICATION NO. (T_{Test})</th><th rowspan="2">NBS THERMOMETER SERIAL NO. (T_{STD})</th><th rowspan="2">DATE (MMDDYY)</th><th rowspan="2">INITIALS OF CALIBRATOR</th><th colspan="2">CALIBRATION DATA</th></tr>
<tr><th>MEASURED °F T_{Test}</th><th>MEASURED °F T_{STD}</th></tr>
<tr><td>204</td><td>579609</td><td>102982</td><td>Gt</td><td>32.9</td><td>33.0</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>201.5</td><td>198.2</td></tr>
<tr><td></td><td>A03864</td><td></td><td></td><td>357</td><td>348</td></tr>
<tr><td>205</td><td>579609</td><td></td><td></td><td>33.0</td><td>33.0</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>202</td><td>199.0</td></tr>
<tr><td></td><td>A03864</td><td></td><td></td><td>355</td><td>345</td></tr>
<tr><td>K114</td><td>579609</td><td></td><td></td><td>33.8</td><td>33.8</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>201</td><td>198.4</td></tr>
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<tr><td>K115</td><td>579609</td><td></td><td></td><td>33.5</td><td>33.4</td></tr>
<tr><td></td><td>565139</td><td></td><td></td><td>201</td><td>198.6</td></tr>
<tr><td></td><td>A03864</td><td></td><td></td><td>363</td><td>353</td></tr>
</table>

Temperature Calibration Data Sheet Form I

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DATE: 102982 OPERATOR INITIALS: Cjt

TYPE OF MAGNEHELIC (CIRCLE ONE): ΔP , ΔH , SPARE

MAGNEHELIC I.D. NO. ① 0727857753 ~~0773~~ RANGE: 0-25 " H_2O

REFERENCE MANOMETER ΔP_1	MAGNEHELIC ΔP_2	% ERROR $\frac{\Delta P_1 - \Delta P_2}{\text{full scale } \Delta P} \times 100$
① 4.6	4.6	0
② 5.7+ 4.2 = 9.9	~~9.9~~ 10.1	0.8%
③ 8.1+6.6 = 14.7	15.2	2.0%
④ 8.9+10.3 = 19.2	19.8	2.4%
⑤ 12.5+11 = 23.5	24.2	2.8%

DATE: 103082 OPERATOR INITIALS: Cjt

TYPE OF MAGNEHELIC (CIRCLE ONE): ΔP , ΔH , SPARE

MAGNEHELIC I.D. NO. 71003RR96. RANGE: 0-10 " H_2O

REFERENCE MANOMETER ΔP_1	MAGNEHELIC ΔP_2	% ERROR $\frac{\Delta P_1 - \Delta P_2}{\text{full scale } \Delta P} \times 100$
① 1.0	0.9	1.0%
② 2.4	2.3	1.0%
③ 1.6+2.6 = 4.2	4.1	1.0%
④ 2.7+3.7 = 6.4	6.4	0 %
⑤ 3.9+ 4.9 = 8.8	8.9	1.0%

Magnehelic Calibration Sheet Form I

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DATE: 103082 OPERATOR INITIALS: gt

TYPE OF MAGNEHELIC (CIRCLE ONE): ΔP, ΔH, SPARE

MAGNEHELIC I.D. NO. 60402A192 RANGE: 0-10 " H_2O

	REFERENCE MANOMETER ΔP_1	MAGNEHELIC ΔP_2	% ERROR $\frac{\Delta P_1 - \Delta P_2}{\text{full scale } \Delta P} \times 100$
①			
②			
③			
④			
⑤			

DATE: 103082 OPERATOR INITIALS: gt

TYPE OF MAGNEHELIC (CIRCLE ONE): ΔP, ΔH, SPARE

MAGNEHELIC I.D. NO. 60402A192 RANGE: 0-10 " H_2O

	REFERENCE MANOMETER ΔP_1	MAGNEHELIC ΔP_2	% ERROR $\frac{\Delta P_1 - \Delta P_2}{\text{full scale } \Delta P} \times 100$
①	1.4	1.4	0
②	3.0	3.0	0
③	5.0	5.0	0
④	3.9+2.9 =6.8	6.9	1.0%
⑤	8.9	9.1	2.0%

Magnehelic Calibration Sheet Form I

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